

# Searching for Cosmic Rays

## Teacher Pack

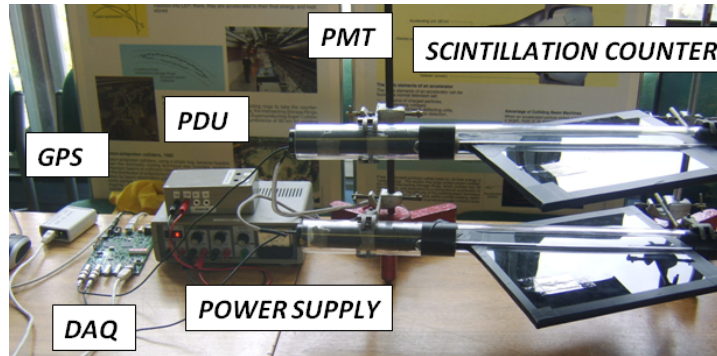


THE UNIVERSITY  
OF BIRMINGHAM

Written by James McCarthy for the University of Birmingham. Developed from Quarknet by Fermilab.



# 1 Introduction to the Project



This project involves using a Cosmic Ray Muon Detector (CRMD) to detect and perform experiments on muons produced when primary cosmic rays interact in the atmosphere. The detector involves 4 scintillation counters and a data acquisition board (DAQ) set up as shown above. The counters are made up of a scintillating material, which emits a flash of light when a charged particle like a muon passes through. This light is then detected by a photomultiplier tube which converts it into a signal. That signal is then fed into the DAQ board and processed. The board can check for coincidences in time between the signals. Since a muon is travelling at nearly the speed of light, they will pass through all the detectors at essentially the same time. The DAQ board then looks for signals which come from all detectors within a short time (about 100ns) as evidence that a muon has passed through. Information from the DAQ board is then fed into the computer through a USB port and can be viewed using a terminal emulator such as Hyperterm. More information about how to use Hyperterm can be found in the appendix.

The great thing about this project is the Cosmic e-lab website, which is the resource which allows you to analyse the data you collect and easily plot graphs using off site computing power. This allows you to quickly and easily analyse the data that students collect. They can obtain a plot of the flux of cosmic rays over time, test the performance of the counters, calculate the lifetime of a muon, look for air showers produced by high energy primary cosmic rays and produce posters to present their results. The address for this website is <http://www18.i2u2.org/elab/cosmic/home/project.jsp>. This project does not only teach the pupils about muons and cosmic rays, but it also introduced them to how particle physics experiments are carried out. They will understand how large scale collaborations work and how we actually detect particles which we can't see.

This pack is aimed at teachers to help you let your students get as much as possible out of the project. I have included students' learning outcomes, possible ways of running the project and detailed descriptions of how to set up and use the detector, and how to use the Cosmic e-lab website. I have also included all of the worksheets in the Student Pack, but with extra annotations (in *italic*) which describe how long each section should take, possible downfalls etc.

## 1.1 Student Prior Knowledge and Skills

Before doing this project, students should know how to:

- Make basic measurements.
- Make basic calculations.
- Interpret basic graphs.
- Write a research question.
- Make a research plan.

## 1.2 Learning Outcomes

Students will know and be able to:

- Content and Investigation:
  - Identify cosmic ray sources and describe how the resulting muons are created in the atmosphere.
  - Explain what the cosmic ray detector measures.
  - Manipulate the data in a way that helps them understand characteristics of the muon.
  - Design an investigation that asks a testable hypothesis, which can be answered from the cosmic ray data and provides a description of cosmic ray phenomena.
- Process:
  - Explain the data collection process including what corrections need to be made in order to obtain reliable data.
  - Evaluate the data to decide which are reliable/usable and which are not and explain how they arrived at the decision to include some data and exclude others.
  - Collect, organize and analyze data to obtain meaningful findings.
  - Use the data to provide evidence to support their claims.
- Computing:
  - Explain why they used specific computing resources in their analysis.
- Literacy:
  - Demonstrate an ability to express meaning in writing (such as in science notebooks, reports) and come to agreement about meaning with others (such as peer review, discussion).

## 1.3 Possible Project Structure

There are many ways this project could be run, depending on how much time you have and how many students are part of the project.

### 1.3.1 Short Experiment/Demonstration

The first option is to just use the setup as a demonstration experiment in one lesson. It could be shown collecting data and it should be explained exactly how it works. Then students could use the cosmic e-lab website to analyse data which already exists and has been uploaded on the website. Each worksheet in the student pack includes details of some example data to use for each study. This is data which has been recorded by the University of Birmingham and should provide good plots which are easy to understand. The disadvantage of this is that students will not get a chance to take their own data, which can help the students to understand the process much better. However, it can easily fit into 1 hour so is ideal if you only have 1 lesson spare.

### 1.3.2 Short Project

Another option is to run the project over about 4 weeks. The idea here is to split up your class into groups of 2 or 3, depending on how large the class is. The first 2 weeks will be the same for all students. Then they will have a chance to use the detectors to take data for their own research topic, which they suggest themselves. It could be investigating a factor which affects the flux of cosmic rays, calculating the lifetime of a muon or investigating air showers. They may need to take data with different settings, and so will need to work together to decide who can use the detector and when. Finally, they can make a poster and present their results to their class mates.

- **Week 1:** Introduction to the project. Teach them the theory behind it and how the detector works. They can play about with the detector and the website to get used to using it. Before they can use the website, they will need to take the preliminary test. This will allow you to find out what they know before the project starts. They can also write a short research proposal including what they will want to investigate and how they plan to investigate it. Work for this week is covered in Worksheet 1 of the student pack.
- **Week 2:** Calibrating and testing the counters. Worksheet 2 teaches how to plateau the counters to find their optimum operating voltages. Worksheet 3 describes how to use the cosmic e-lab website to test the counters to ensure they are working well.
- **Week 3:** This is when they use the detector to answer the research question they posed in week 1. They may need to carry out their experiments at different times as each group will probably need to take different data. This will encourage collaboration to organise who can have the detector when and to see if some data can be reused for different groups. Different methods of collecting data are described in Worksheet 4 - 6.
- **Week 4:** They can use the e-lab website to create a poster displaying their results. This is described in Worksheet 7. They can end the week by presenting their results to their classmates, by showing their poster and preparing a short talk describing how they obtained those results. This is a nice way to round off the project and means that all students learn from the other groups.

### 1.3.3 Long Project

This project would run for 7 or 8 weeks and is ideal if you only have a small number of students. It is suggested that it could be run as an after school activity, so that you have time to fit in your curriculum. There are 7 worksheets in total, and it shouldn't take more than an hour or two to work through them (except Worksheet 2: plateauing the counter, this takes a few hours). The project should therefore last about 7 weeks, unless you aim to get through 2 worksheets each week. This time does not include the time it takes to collect data, but once the data is being recorded, the experiment can be left to run. You may need to organise it so that you split one worksheet into 2 sessions. The first session will be an introduction to the worksheet and using data already uploaded to learn how to run the analysis. They can then set up the detector, leave it recording data and analyse the data in the next session.

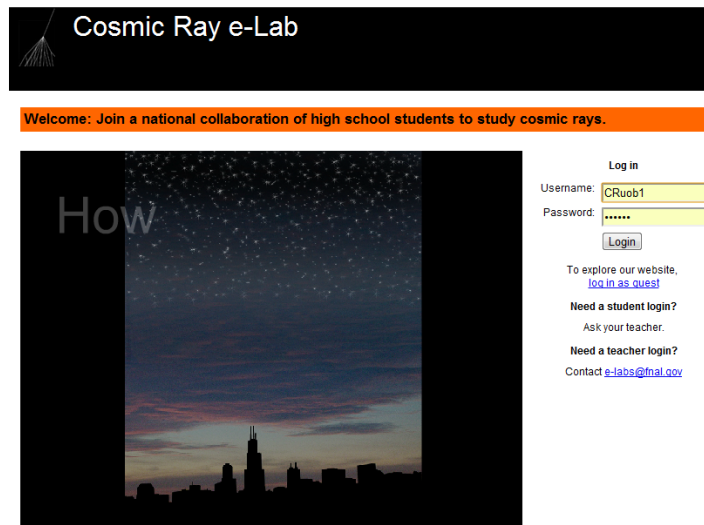
## 1.4 Using the Cosmic e-lab Website

The Cosmic e-lab website is the main resource for analysing data from the detector. The website is <http://www18.i2u2.org/elab/cosmic/home/project.jsp>. Hyperterm is used to record data to a .txt file which can then be uploaded and analysed. There are two sections of the website, the Student Home and the Teacher Home. If you do not have a password for a teacher account please get in touch with the University of Birmingham.

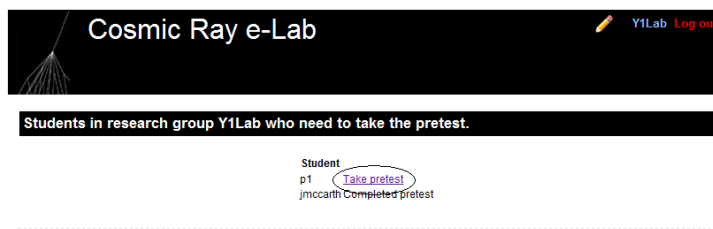
### 1.4.1 Student Home

*This section is taken from Worksheet 1 of the student pack, and provides all the information for using the website. Specific analysis options are discussed in the relevant worksheets*

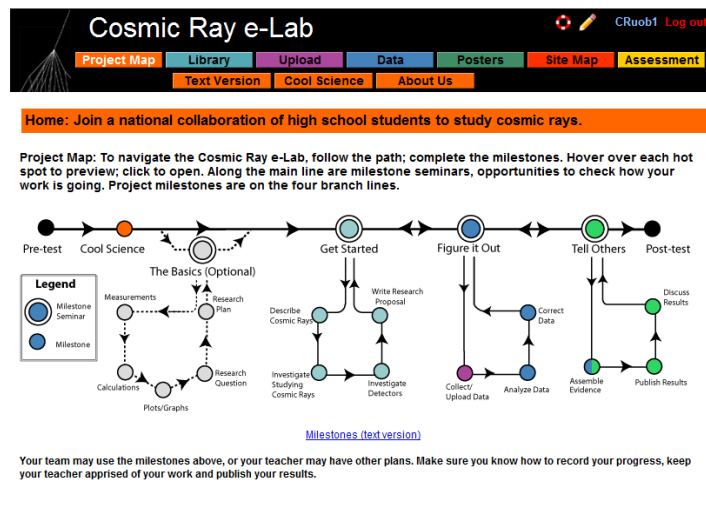
Your most valuable tool for this project is going to be the cosmic ray e-lab website. This contains all the resources you need to get your head around cosmic rays, and contains the tools to analyse the data you collect. The website is <http://www18.i2u2.org/elab/cosmic/home/>



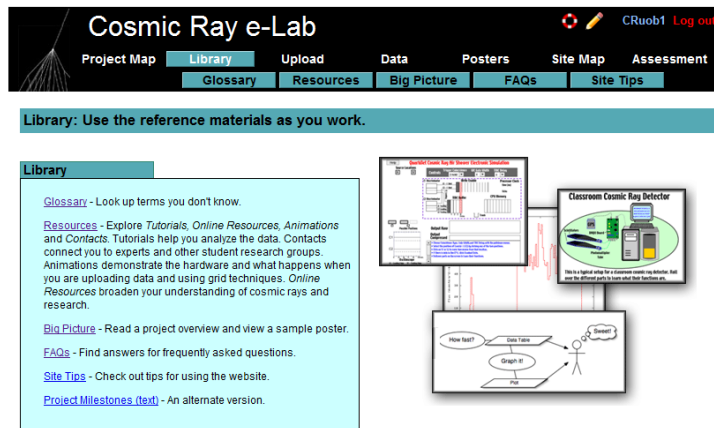
You teacher will be able to provide you with the details you need to log into the website.



If it is your first time logging on then you will need to complete a short pre-test, just to establish what you already know before you start the project. Everybody in your group will need to complete the test before you can start.



The first page you are presented with is then the project map. This shows you the various milestones you are expected to complete through the project. Clicking on each of the circles will give you more information about that milestone.

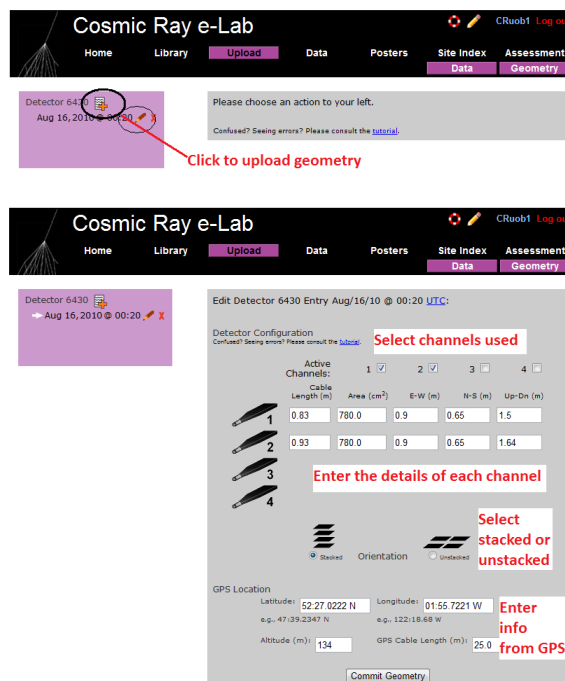


By clicking on the “library” tab at the top of the page, you can access all of the learning resources available on the site. The glossary contains a list of technical terms along with what they mean, and the resources page contains useful information about cosmic rays, and step-by-step tutorials about how to use the website. Refer to this section if you ever need help navigating through the site or using the analysis tools, and you cannot find the information in this Student Pack. It would be a good idea to spend some time getting yourself familiar with the website and the tools available to you.

### 1.4.2 Uploading the geometry of the detectors

Once you have the detector set up and working, you need to enter the geometry of the detector into the e-lab website. It is essential that this is correct, since they use the information to calculate the flux of muons from the data you collect.

- To upload the geometry of the detector click on the upload tab on the e-lab website and then click on the geometry tab.
- Click on “add entry”.

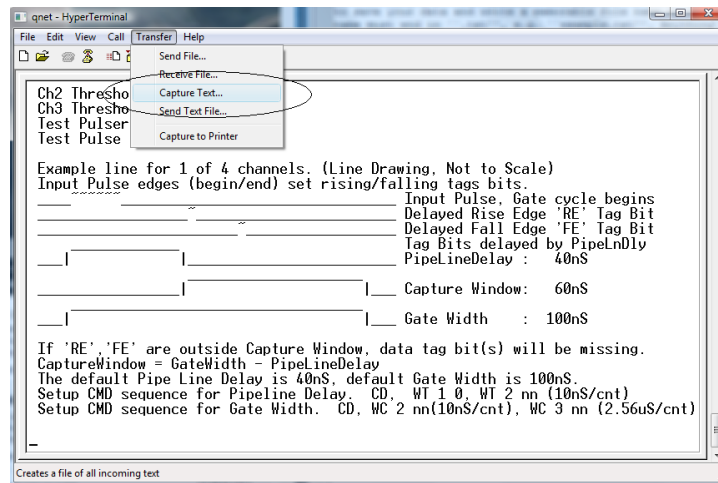


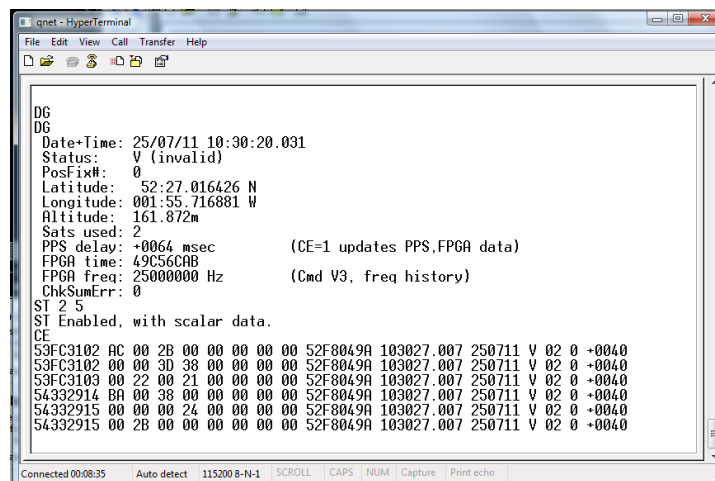
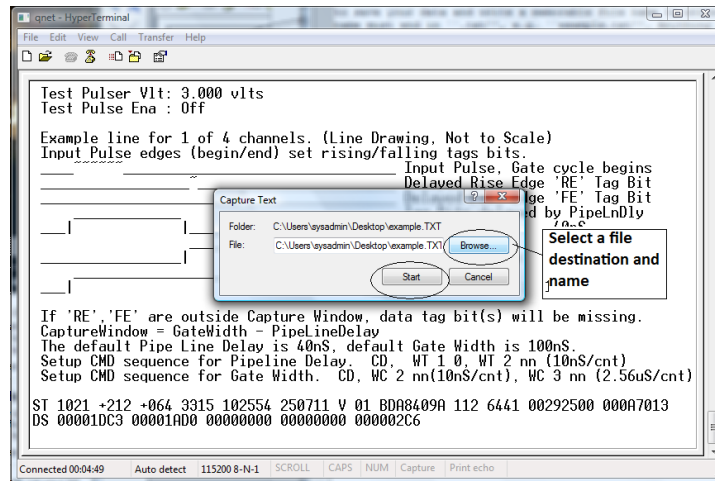
- Fill in the details of the detector setup. First, tick the boxes corresponding to the channels which you are using.
- Next, enter the required details for each counter.
- The cable length is the length of cable from the PMT to the DAQ board.
- The area is the surface area of the counter in units of  $\text{cm}^2$ .
- The E-W (East-West), N-S (North-South) and Up-Down measurements are the distances of the counters from the GPS antenna. The values do not have to be completely accurate but difference between the Up-Down measurements of your counters should be the distance between the counters, which you can measure quite accurately.
- Next you need to select the orientation of the detector. Select stacked if the counters are on top of each other or unstacked if they are all on the same level. To start with, your detector should be stacked.
- Finally, you need to enter details of the GPS antenna. The longitude, latitude and altitude measurements can be found by typing the DG command into Hyperterm.
- The GPS cable length is the length of cable connecting the GPS module to the DAQ board.

### 1.4.3 Collecting data

Now that the detectors are set up and the geometry has been uploaded to the website, you are ready to start taking data.

- Open up Hyperterm.
- From the “Transfer” menu, select “Capture Text”. Choose where you want to save your data and write a memorable file name to write the data to. The file name must end in “.txt”, e.g. “example.txt”. Anything that now appears on the Hyperterm screen will also be saved to the file you selected.





- Before you start taking any data, you need to enter the following commands:
  - V1
  - V2
  - DG
  - ST 2 5
- The first 3 commands display information about the status of the detector, which is needed by the website to analyse your data. The last command writes out a status line every 5 minutes, which is also required during analysis of the data you collect.
- You can now start reading out the data from the counters by typing the command CE. Now, everytime the counters detect a cosmic ray muon, data about the signal received will be shown on the screen and recorded in the text file.
- You can then leave the detector running and collecting data for as long as you wish. Just remember that the more data you take, the more accurate your results will be, so there is an advantage to leaving the detector running for as long as you can.
- Once you have collected enough data, tpe the command CD to stop reading the data to the screen.
- Now select “Stop” from the Transfer menu in order to stop recording the data.

#### 1.4.4 Analysing data

Now that you have your data recorded on a file, you can upload it to the e-lab website for analysis.

- Click on the upload tab, and then click on data.
- Now select the file that you recorded the data and on click on “upload”.

Cosmic Ray e-Lab

Project Map Library **Upload** Data Posters Site Map Assessment

**Upload raw data collected by your cosmic ray detector.**

- Select the detector associated with the data you are uploading.
- Click Choose File/Browse to locate the data file on your computer.
- Click Upload to upload the file.

Please do not upload files larger than 2 GB in size. You'll have to split them up into smaller pieces. Questions? See the [FAQ](#)

Choose detector  
6430

Raw Data File: Choose File No file chosen

Optional comments on raw data:

**Select your detector and click to find your data file**

**Once you have selected your file click on "Upload"**

Upload

#### 1.4.5 Teacher Home

HELPDESK', 'Use this Cosmic Ray e-Lab URL: [www.izu2.org/elab/cosmic](#)', and 'Published Mon Aug 01 13:00:00 CDT 2011'."/>

Cosmic Ray e-Lab

Teacher Home **Share Ideas** Standards Site Index Registration

**Teacher Home - Bookmark It!**

Click on each topic or its arrow to expand it. Click again to collapse it. Click on **Expand All Topics** or **Collapse All Topics** to expand or collapse all the content on the page. These only work when you have Javascript enabled in your web browser.

[Expand All Topics](#)

**e-Lab Summary**

- » [Introduction to Cosmic Ray Research](#)
- » [Good Research Questions](#)
- » [Student Prior Knowledge and Skills](#)
- » [Learner Outcomes and Assessment](#)
- » [Suggestions for Getting Started](#)
- » [Navigating Students Through the e-Lab](#)
- » [Help Desk & Sharing Ideas](#)
- » [e-Lab Technology Requirements](#)

**News Alert**

**All Cosmic Ray Muon Detector owners**

Reminder -- include these commands with all data-taking:  
ST 2 5  
TL  
SA 1

This will embed status lines in the raw data needed to "bless" your data.

Send concerns to: [HELPDESK](#)

Use this Cosmic Ray e-Lab URL: [www.izu2.org/elab/cosmic](#)

Published Mon Aug 01 13:00:00 CDT 2011

When you log onto a teach account, you are first presented with the Teacher Home. This page contains a lot of the information you need about the project. Expand each section to get more advice on how to get the most out of the project. You can also access the Student Home page to use the same resources available to the students.

### 1.4.6 Registering Students and Groups

The screenshot shows the Cosmic Ray e-Lab website with a dark header. The header contains the site logo, navigation links (Teacher Home, Share Ideas, Standards, Site Index, Registration), and a user profile (CRuob1 Log out). Below the header is a black bar with the text "e-Lab Registration". The main content area has a light background and contains several links: "Register student research groups", "Update your previously created groups", "Assign your research groups to new e-Labs", and "Update detector IDs for your group". To the right of these links is a block of text explaining the registration process: "Use this page to register less than ten students. You can link new students to existing research groups or you can create new research groups for students. Update your research groups. When you register a group, they are registered for the current e-Lab. If you want to register them for new e-Labs as more become available, you need to use this page. When you analyze data in the Cosmic Ray e-Lab, most of the analyses need to know information about your detector. This page allows you to assign detector IDs to your group."

Click on the “Registration” tab to create or update groups and to add or remove students to groups. Having groups of students helps you to easily keep track of who is uploading and analysing which data.

This screenshot shows the registration process on the Cosmic Ray e-Lab website. The header is the same as the previous screenshot. Below the header, there is a list of instructions: "Register new students below. To register more students, click on the + button.", "We will create new groups and their associated passwords for you.", "Select [icon] if you want to grant the new group upload permissions for your detectors.", and "Select [icon] if you want the new group to take the pre-test." Below these instructions are input fields for "First Name" and "Last Name", a "Choose group" dropdown menu, and a "Make New Group" button. There is also a "+" button and an "I'm done" button.

Click on “Register student research groups” to add students to an existing group or create a new group. Just type the students name and select the group your wish to add them to. To add them to a new group, click “Make new group” and enter the group name you want. Tick the two boxes to say that the students can upload data and take the pre-test. There is more information on the pre-tests in the next section. The system will automatically make a password for this group to log into the e-lab website with the group name as a username. You can change the settings and password at a later date if needed. You can now add more students to this group from the same page.

The screenshot shows the "Update your groups" page on the Cosmic Ray e-Lab website. The header is the same as the previous screenshots. Below the header, there is a black bar with the text "Update your groups". The main content area has a light background and contains a form for updating a group. The form includes a dropdown menu for "Y1Lab", a "Show Group Info" button, and fields for "Group Name", "Academic Year", "Role", "Upload", "In survey", "Password", and "Verify Password". There are also radio buttons for "User" and "No/Yes" options. At the bottom, there is a checkbox for "Students to delete from 'Y1Lab'" and a button for "Update Group Information".

From the registration page click on “Update your previously created groups” to change anything about a group. Select the group you want to update and click on “Show Group Info”. You can change the academic year the group belongs to, their uploading permissions or their password. If you select the tick boxes next to the pupils name then that student will be deleted from the group. When you are done, click on “Update Group Information”.

Cosmic Ray e-Lab

Teacher Home i2U2 Home Share Ideas Project Home Standards Student Home Site Index Registration

Update the e-Lab Assignment for your groups.

CRuob1 Show Group Info

Group Name: CRuob1

e-Labs for CRuob1: ☒ cosmic ☐ cms ☐ ligo ☐ cms-lb

Update e-Lab Assignments

You can change the e-lab each group can use by clicking on “Assign your research groups to new e-Labs”. Click on “Show Group Info” and click on the e-labs you want to use. We only need to use the cosmic e-lab.

Cosmic Ray e-Lab

Teacher Home i2U2 Home Share Ideas Project Home Standards Student Home Site Index Registration

Update your groups

Successfully updated DAQ ID(s) for group "CRuob1".

Every [DAQ](#) board has a detector id (DAQ number) based on the serial number on the board. Students select it when they upload data. To find it, type "SN" when connected with your detector.

CRuob1 Show Group Info

Group Name: CRuob1

Detector ID(s) for CRuob1 (comma or space separated): 6411, 6430

Update Group Detector IDs

You can assign the detector serial numbers to your groups by clicking on “Update detector IDs for your group” from the registration page. The number of the detector is on the bottom of the DAQ board, or it can be found by typing SN in Hyperterm. Type in the correct serial number and click on “Update Group Detector IDs”.

#### 1.4.7 Preliminary Tests

Before the students start the project they all need to take a pretest, which is a set of 21 multiple choice questions about experimentation methods and cosmic rays. The aim is to find out how much the students already know before they start the project. They can then take the same test again at the end of the project to see how their knowledge has improved.

- **Introduction to Cosmic Ray Research**
- **Good Research Questions**
- **Student Prior Knowledge and Skills**
- ▼ **Learner Outcomes and Assessment**

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This will emit  
raw data near  
data.  
Send concern  
Use this Cos  
www.i2u2.org  
Published Mon /  
2011

Students will know and be able to:

- **Content and Investigation:**
  - Identify cosmic ray sources and describe how the resulting muons are created in the atmosphere.
  - Explain what the cosmic ray detector measures.
  - Manipulate the data in a way that helps them understand characteristics of the muon.
  - Design an investigation that asks a testable hypothesis, which can be answered from the cosmic ray data and provides a description of cosmic ray phenomena.
- **Process:**
  - Explain the data collection process including what corrections need to be made in order to obtain reliable data.
  - Evaluate the data to decide which are reliable/usable and which are not and explain how they arrived at the decision to include some data and exclude others.
  - Collect, organize and analyze data to obtain meaningful findings.
  - Use the data to provide evidence to support their claims.
- **Computing:**
  - Explain why they used specific computing resources in their analysis.
- **Literacy:**
  - Demonstrate an ability to express meaning in writing (such as in science notebooks, reports) and come to agreement about meaning with others (such as peer review, discussion).

Assessment is aligned to learner outcomes. While many teachers will want to design their own assessments, we provide some options.

- **Rubrics:** Content & Investigation, Process, Computing, Literacy
- **Tests (for groups created before Summer 2009):** Pre- and post-tests of content knowledge and student results for pre- and post-tests.
- **Tests (for groups created after Summer 2009):** Pre- and post-tests of content knowledge and student results for pre- and post-tests.
- **e-Logbooks:** Track progress and provide feedback on student work. Review students' evidence of what they have understood and reflections on their research. Review all students' entries. Click to view the results ray descriptions, and make notes in your logbook for next year. Look at this sample logbook.
- **Milestone Seminars:** Check student understanding before they move from one section of the project milestones to another.

Click to view the questions

Click to view the results

#### ► **Suggestions for Getting Started**

**Navigating Students Through the e-Lab**

► **Help Desk & Sharing Ideas**

► **e-Lab Technology Requirements**

[Teacher Home](#)
[Share Ideas](#)
[Standards](#)
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[Registration](#)

[Log out](#)

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**Your students' pre-test results**

Students' answers are listed under each question. Click on the answer to see the question and answers. Correct answers are displayed in green; incorrect answers are displayed in red. The black and white version uses + and - signs so that correct answers can be seen when printed on a black and white printer.

Research Group	Student Name	Correct/Total	Answers
Y1Lab	imccarth	13/21	<div style="display: flex; gap: 2px;"> <span>Q1</span><span>Q2</span><span>Q3</span><span>Q4</span><span>Q5</span><span>Q6</span><span>Q7</span><span>Q8</span><span>Q9</span><span>Q10</span><span>Q11</span><span>Q12</span><span>Q13</span><span>Q14</span><span>Q15</span><span>Q16</span><span>Q17</span> </div> <div style="display: flex; gap: 2px;"> <span>Q18</span><span>Q19</span><span>Q20</span><span>Q21</span> </div>

[Printable version](#) (opens in new window)

You can view the test, and the results of the tests, from the “Learner Outcomes and Assessment”. Click the links to either view the questions or to view the students’ results. From the results page you can see exactly which questions the student answered correctly. By clicking the questions you can view the student’s answer plus the correct answer.

*The next pages are the worksheets from the student pack. They have been annotated with italics with some useful comments. The first worksheet is an introduction to the project. It is designed to be a useful revision tool, but most of the material can be taught at the board to enhance their understanding. It is also a good idea to take advantage of the opportunity for them to log onto the cosmic e-lab website and let them investigate what exactly can be done. If there is time, ask them to set up the muon detector themselves. Instructions can be found in the appendix. This will give them the chance to familiarise themselves with the different parts of the detector and hopefully help them to understand how it works.*



## 2 Worksheet 2: Plateauing the Counter

*The aim of this worksheet is to get the pupils to find the optimum operating voltage to use for each counter. This is done by using a method called “plateauing the counters”. This exercise helps them to understand how the PMT works, but it is possible to continue without carrying out this experiment. If this experiment is skipped then the following control voltages should be used:*

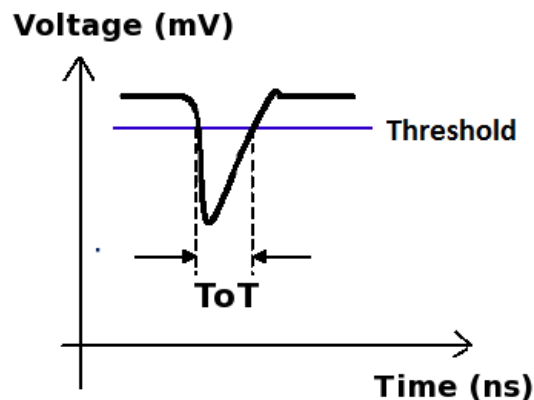
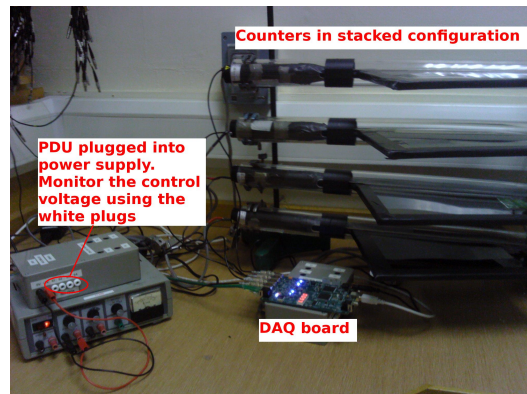
- S1: 0.9V
- S2: 0.95V
- S3: 0.85V
- S4: 0.9V

*It is possible to plateau 2 counters in about an hour. I would suggest splitting the class into 2 groups, plateauing 2 counters each.*

### 2.1 Aim

Before you use any detector you need to make sure that it is set up properly and working correctly. Otherwise, you cannot trust the data which you are recording. When you come to present your results, nobody will accept them unless you can show that the detector is working as expected. The aim of this worksheet is to find the optimum operating conditions for your detector. For this worksheet you will need a stopwatch.

### 2.2 The Control Voltage

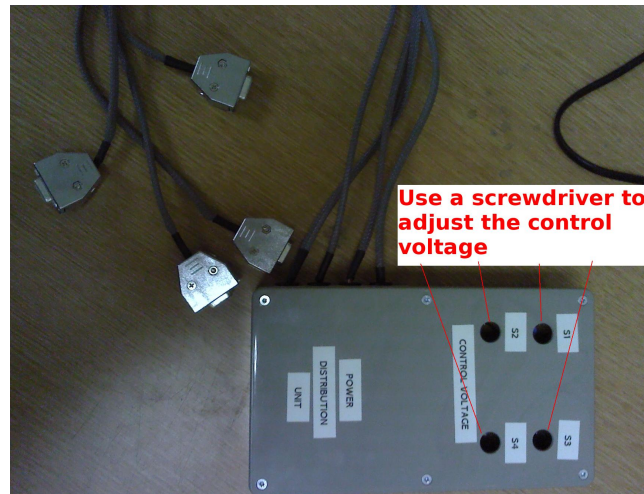


The aim of the Power Distribution Unit (PDU) is to apply a voltage across the photomultiplier tube, called the control voltage. The size of the signal produced by the PMT is determined by the control voltage, the higher the voltage, the larger the signals will be. Usually, signals which are produced when muons pass through the scintillator will be quite large. Signals which are produced by other sources tend to be smaller. Since we are not interested in these types of signals, they are usually called *noise*, and they get in the way of detecting the cosmic rays. We therefore want to ignore these small signals and only count large signals from muons. To do this, the DAQ board only accepts signals above a certain threshold, which is by default set to 300mV. Noise signals will usually be below this, and so will be ignored by the card. However, if the control voltage is set too low, then the signals produced by cosmic rays will be below the threshold, and so we will not detect every particle which passes through. Conversely, if the control voltage is too high then the noise signals will be above the threshold and so will be incorrectly counted as cosmic rays. At the same time, operating at a high voltage puts a lot of strain on the PMTs, so to extend their lifetime we need to operate at the lowest voltage possible while still detecting as many cosmic rays as we can. To find this optimum control voltage we go through a process called “Plateauing the counters”. The reason for calling it this will soon become apparent.

## 2.3 Finding the Plateau



In order to plateau a counter, you need to set up the detector with 2 counters, one on top of the other. One will be the counter which you want to plateau, which we will call Counter 1, and the other will be your reference counter, which we will call Counter 2.



You can test the control voltage on each counter by plugging a digital multimeter (DMM) into the PDU across the 0V (black) and control voltage (white) plugs. Each counter has a separate

plug for its control voltage. The control voltage can then be changed by turning the corresponding variable resistor in the PDU.

Follow the steps below to plateau the first counter:

1. Set the control voltage across Counter 2 to 1V.
2. Set the control voltage across Counter 1 to 0.65V
3. Open up hyperterminal. Details of how to use hyperterminal can be found in the appendix to this pack. Type WC 00 13, which will set up the DAQ board to look for coincidences between the two counters.
4. Type TL 4 300 to set the threshold of all 4 counters to 300mV.

```

V1
Run Mode      : 0n
Ch(s) Enabled : 1,0
Veto Enable   : Off
Veto Select   : Ch0
Coincidence 1-4 : 2-Fold
Pipe Line Delay : 40 nS
Gate Width    : 100 nS
Ch0 Threshold : 0.300 vltS
Ch1 Threshold : 0.300 vltS
Ch2 Threshold : 0.300 vltS
Ch3 Threshold : 0.300 vltS
Test Pulser V1t : 3.000 vltS
Test Pulse Ena : Off

Example line for 1 of 4 channels. (Line Drawing, Not to Scale)
Input Pulse edges (begin/end) set rising/falling tags bits.
_____ Input Pulse, Gate cycle begins
_____ Delayed Rise Edge 'RE' Tag Bit
_____ Delayed Fall Edge 'FE' Tag Bit
_____ Tag Bits delayed by PipeLnDly
_____ PipeLineDelay : 40nS
_____ Capture Window: 60nS
_____ Gate Width : 100nS

If 'RE', 'FE' are outside Capture Window, data tag bit(s) will be missing.
CaptureWindow = GateWidth - PipeLineDelay
The default Pipe Line Delay is 40nS, default Gate Width is 100nS.
Setup CMD sequence for PipeLine Delay. CD, WT 1 0, WT 2 nn (10nS/cnt)
Setup CMD sequence for Gate Width. CD, WC 2 nn(10nS/cnt), WC 3 nn (2.56uS/cnt)
  
```

5. Type V1 to check that the last two commands worked.
6. We now need to find out how many cosmic rays are detected in a minute. The DAQ board starts counting as soon as the counters are plugged in. To start the counters again you can use the command RB. Type RB and start the stopwatch at the same time.

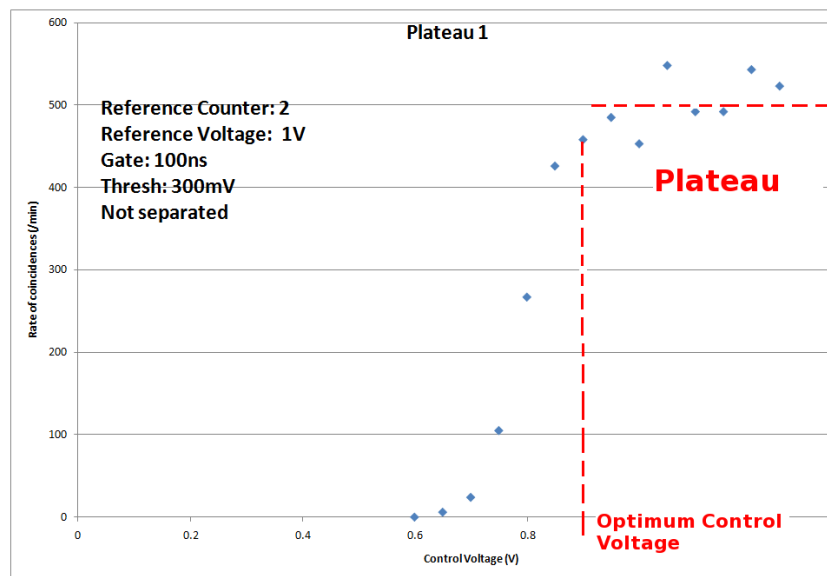
```

Example line for 1 of 4 channels. (Line Drawing, Not to Scale)
Input Pulse edges (begin/end) set rising/falling tags bits.
_____ Input Pulse, Gate cycle begins
_____ Delayed Rise Edge 'RE' Tag Bit
_____ Delayed Fall Edge 'FE' Tag Bit
_____ Tag Bits delayed by PipeLnDly
_____ PipeLineDelay : 40nS
_____ Capture Window: 60nS
_____ Gate Width : 100nS

If 'RE', 'FE' are outside Capture Window, data tag bit(s) will be missing.
CaptureWindow = GateWidth - PipeLineDelay
The default Pipe Line Delay is 40nS, default Gate Width is 100nS.
Setup CMD sequence for PipeLine Delay. CD, WT 1 0, WT 2 nn (10nS/cnt)
Setup CMD sequence for Gate Width. CD, WC 2 nn(10nS/cnt), WC 3 nn (2.56uS/cnt)

Type RB to reset the counters
RB
DS S0=0069CACE S1=00000369 S2=00000000 S3=00000000 S4=000000C6 S5=33CF5098
RB
  
```

7. After one minute, type the command DS. This displays the counters on the board and tells you how many cosmic rays have been seen. The numbers are all in a hexadecimal format. The value of S4 is the number of coincidences, i.e. the number of cosmic rays detected.
8. Type the value of the control voltage and the value of S4 into MS Excel. Use the hex2dec() function to convert the flux into a decimal number.
9. Increase the control voltage across Counter 1 to 0.6V and repeat the process to find out how many coincidences there are in a minute.
10. Repeat this until you reach a control voltage of 1.3V
11. Now use MS Excel to obtain a plot of counts per minute against control voltage.



The plateau they obtain should be similar to the one above. We have noticed that the PMTs are quite noisy, meaning you do not get a perfectly level plateau. It is also very sensitive to the reference voltage used on the other counter. If the plot they obtain is rising too sharply then you can try again with a slightly lower reference voltage.

Your plot should look similar to the one above. There should be very few counts below a certain point, and when the control voltage is large enough that the signals are above the threshold, then the counts per minute should increase. The counts per minute should level off when all the cosmic rays are being detected. This levelling off is called the plateau. The operating voltage should be set to the voltage just above where the plateau begins.

You can now plateau the other counters using Counter 1 as a reference counter. Set the control voltage across Counter 1 to the optimum voltage found, and use it to plateau the other counters.

### 3 Worksheet 4: Flux Study

*This worksheet describes different methods of measuring the cosmic ray flux. It can be done by recording data to be uploaded to the cosmic e-lab, or simply by reading the scalars on the DAQ board after 1 minute. The main point of this experiment is for them to come up with a research topic of their own. They can investigate any factor which they think will affect the cosmic ray flux. I would be a good exercise to get them to write a short research proposal, including what they are investigating, how they plan to investigate it and what they expect to find. This will make them think about the best way to carry out the investigation, and will give you the chance to steer them in the right direction. The amount of data they need to record will depend on what it is they are investigating. This will need to be taken into account when running the project. Also, since there is only one detector, if you want each pupil to perform their own study, they will have to organise themselves to each use it at a different time. This worksheet may therefore need to be run over a few sessions.*

#### 3.1 Aim

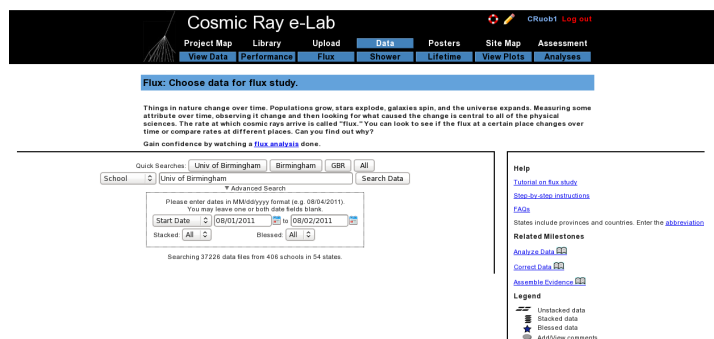
The aim of this worksheet is to find out the flux of cosmic rays and to investigate the different factors which may affect the cosmic ray flux.

#### 3.2 Introduction

The flux of cosmic rays is the number of cosmic rays passing through a certain area at any given time. It can be measured in different units, but we will measure it in units of  $events/m^2/60 - seconds$ . That means we are measuring the number of cosmic rays passing through an area of  $1m^2$  in every minute. Using the tools in the Cosmic e-lab website (<http://www18.i2u2.org/elab/cosmic/home/>) it is possible to measure the cosmic ray flux, and monitor how it changes over time. This is the first thing we will do in the worksheet, and then you will have the opportunity to create your own research question and investigate a factor which affects the cosmic ray flux.

#### 3.3 Running a Flux Study

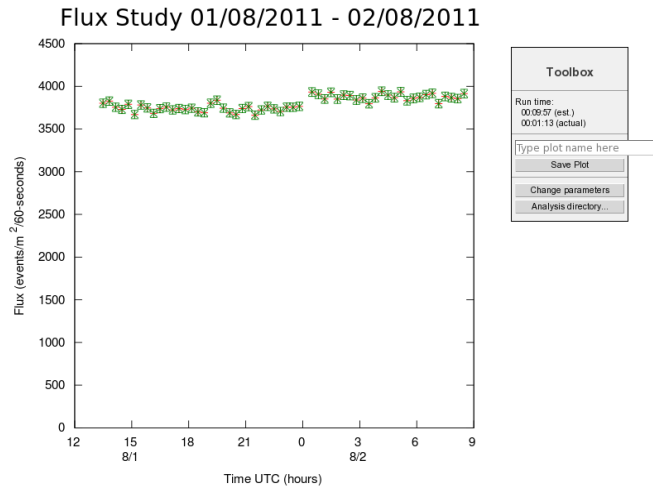
Firstly, we will use some data which has already been uploaded to learn how to perform a flux study. Start by logging onto the e-lab website (<http://www18.i2u2.org/elab/cosmic/home/>).



Click on “Data” and then “Flux”, and you should see the screen above.

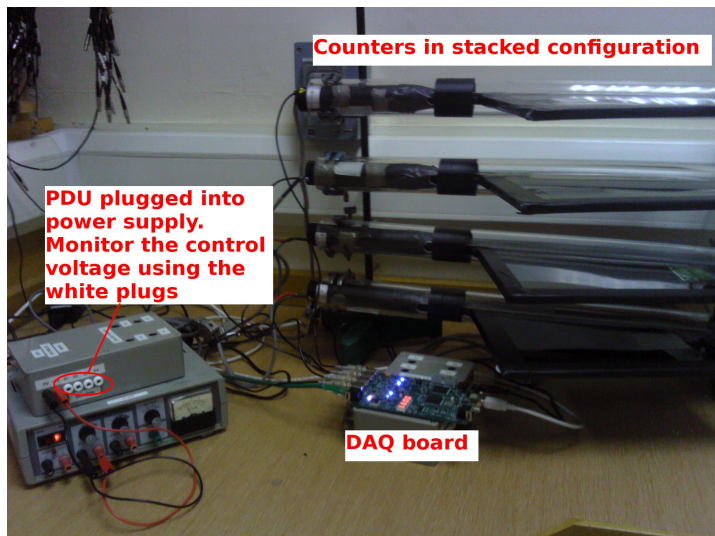
Use the search box to select “School” and find data from the “Univ of Birmingham”. Select the data from 19/08/2011 and click on “Run Flux Study”.

You can change the properties of the plot from the next screen, shown above. If you have collected data over a long period of time, you may want to have a larger bin width, so that the data points are not so cramped. Conversely, if you do not have much data, you may want to use smaller bin widths so that more data points are plotted. Once you have set your own plot title click on “Analyze”

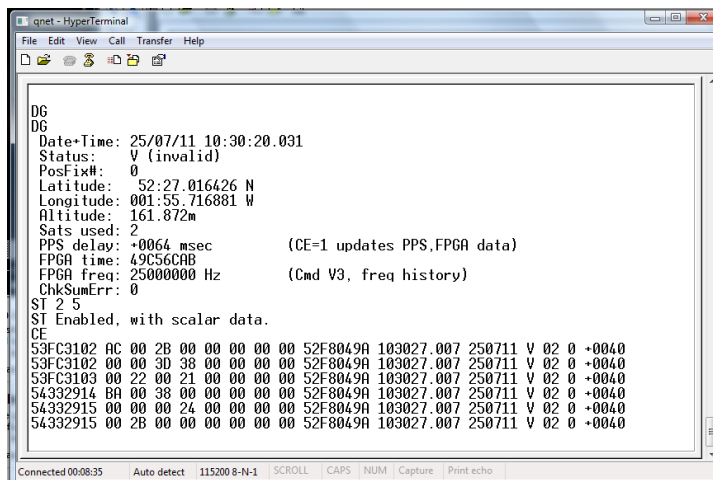
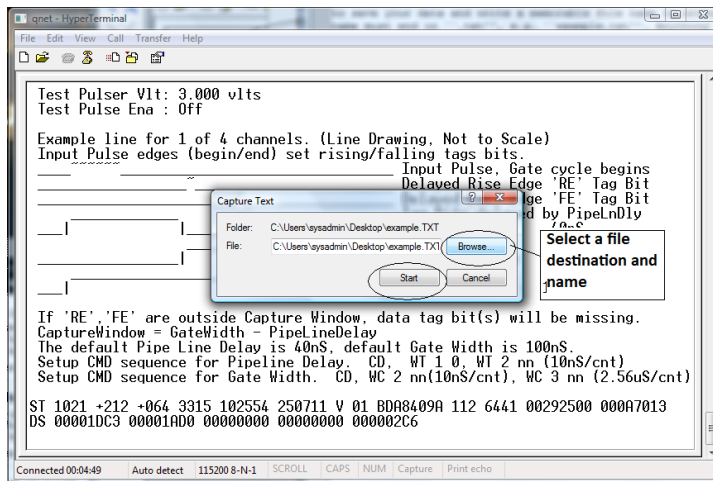
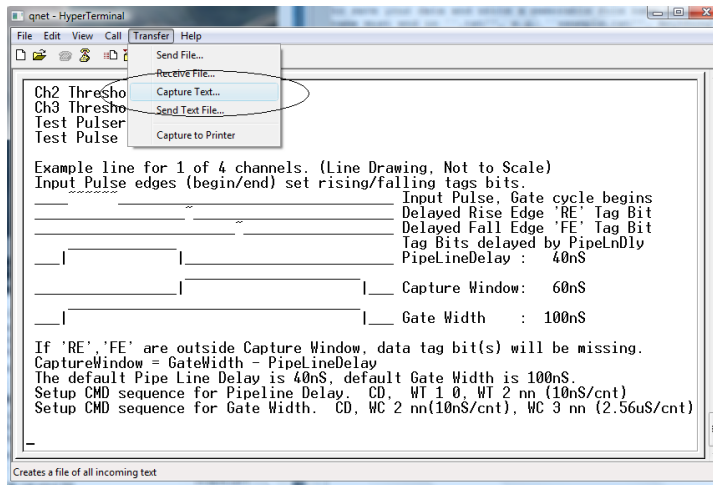


You should obtain a plot which looks like the one above. Click on “Change parameters” to the side if you are not happy with how the graph looks. Now you can take data with your detector to obtain your own flux plot.

### 3.4 Taking your Own Data



Set up your counters in the stacked configuration shown above and set the control voltages to the optimum voltages found by the plateau method. Open Hyperterminal and follow the steps below to collect data:



1. Set up the DAQ board to record 4-fold coincidences by typing WC 00 3F.
2. From the "Transfer" menu select "Capture Text"
3. Choose a file name ending with ".txt" and save your file somewhere memorable. Then select "Start"

- Anything which now appears in the Hyperterminal window will also be written to the “.txt” file. Start by typing the commands V1, V2, DG, ST 2 5. This ensures your data file contains the necessary information about the detectors.
- Type the command CE to enable the counters and start writing data to the “.txt” file. Leave this running for about 2 hours. Make sure that the computer you are using is set to never sleep, otherwise you will not continue to collect data.
- Once you have collected enough data type the command CD to stop writing out data.
- From the “Transfer” menu select “Capture Text” and “Stop”.

Once you have your data, you can upload it to the Cosmic e-lab website. But before you do that you need to upload the geometry.

- To upload the geometry of the detector click on the upload tab on the e-lab website and then click on the geometry tab.
- Click on “add entry”.

**Cosmic Ray e-Lab**

Home Library **Upload** Data Posters Site Index Assessment

Detector 6430 Aug 16, 2010 @ 00:20

Please choose an action to your left.

Confused? Seeing errors? Please consult the [tutorial](#).

**Click to upload geometry**

---

**Cosmic Ray e-Lab**

Home Library **Upload** Data Posters Site Index Assessment

Detector 6430 Aug 16, 2010 @ 00:20

Edit Detector 6430 Entry Aug/16/10 @ 00:20 UTC

Detector Configuration

Confused? Seeing errors? Please consult the [tutorial](#).

**Select channels used**

Active Channels:	1	2	3	4
Cable Length (m)	0.83	780.0	0.9	0.65
Area (cm <sup>2</sup> )	780.0	0.9	0.65	1.5
E-W (m)	0.93	780.0	0.9	0.65
N-S (m)	0.93	780.0	0.9	0.65
Up-Dn (m)	0.93	780.0	0.9	0.65

**Enter the details of each channel**

**Select stacked or unstacked**

Stacked Orientation Unstacked

GPS Location

Latitude: 52.27 0222 N Longitude: 01.55 7221 W

e.g., 47.39:2347 N e.g., 122:16.68 W

Altitude (m): 134 GPS Cable Length (m): 25.0

**Enter info from GPS**

Commit Geometry

- Fill in the details of the detector setup. First, tick the boxes corresponding to the channels which you are using.
- Next, enter the required details for each counter.
- The cable length is the length of cable from the PMT to the DAQ board.
- The area is the surface area of the counter in units of cm<sup>2</sup>.
- The E-W (East-West), N-S (North-South) and Up-Down measurements are the distances of the counters from the GPS antenna. The values do not have to be completely accurate but difference between the Up-Down measurements of your counters should be the distance between the counters, which you can measure quite accurately.

- Next you need to select the orientation of the detector. Select stacked if the counters are on top of each other or unstacked if they are all on the same level. To start with, your detector should be stacked.
- Finally, you need to enter details of the GPS antenna. The longitude, latitude and altitude measurements can be found by typing the DG command into Hyperterm.
- The GPS cable length is the length of cable connecting the GPS module to the DAQ board.

The screenshot shows the 'Cosmic Ray e-Lab' website. The navigation bar includes 'Project Map', 'Library', 'Upload', 'Data', 'Posters', 'Site Map', and 'Assessment'. The 'Upload' tab is active, and the 'Data' sub-tab is selected. Below the navigation bar, a purple banner reads 'Upload raw data collected by your cosmic ray detector.' Below this banner, three instructions are listed: 'Select the detector associated with the data you are uploading.', 'Click Choose File/Browse to locate the data file on your computer.', and 'Click Upload to upload the file.' The main form area contains a warning box: 'Please do not upload files larger than 2 GB in size. You'll have to split them up into smaller pieces. Questions? See the FAQ'. Below the warning, there is a 'Choose detector' dropdown menu with '6430' selected. To the right of the dropdown is a 'Raw Data File:' label, followed by a 'Choose File' button and the text 'No file chosen'. Below this is an 'Optional comments on raw data:' text area. At the bottom of the form is an 'Upload' button. Red annotations with arrows point to the 'Choose detector' dropdown, the 'Choose File' button, and the 'Upload' button. The annotation for the dropdown says 'Select your detector and click to find your data file'. The annotation for the 'Upload' button says 'Once you have selected your file click on "Upload"'.

Upload your data by clicking “Upload” and then “Data”. It is now ready to be analysed. Repeat the steps above with the data you have just taken to obtain your own flux studies. How does the flux you measure compare with the flux measured at the University of Birmingham? Does the flux change over the two hours you were collecting data for. Once you are happy with your plot, click on “Save Plot” so that you can easily access it again.

### 3.5 Alternative Flux Measurements

This is not the only way to measure the flux of cosmic rays. If you merely want to find out the rate of cosmic rays detected by your counters, you can use the DAQ board and Hyperterm.

1. Open up hyperterminal and type WC 00 3F. This will set up the DAQ board to look for coincidences between all 4 counters.
2. We now need to find out how many cosmic rays are detected in a minute. The DAQ board starts counting as soon as the counters are plugged in. To start the counters again you can use the command RB. Type RB and start the stopwatch at the same time.





## 4 Worksheet 5: Measuring the Lifetime of a Muon

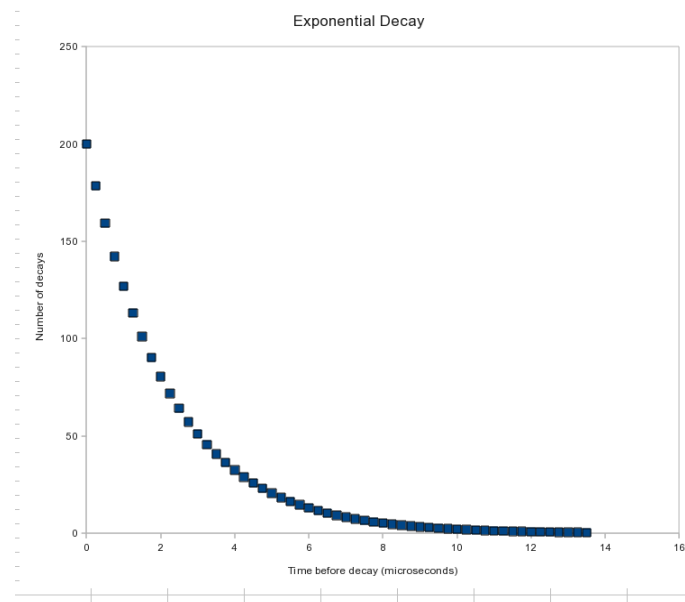
Using the detectors and the cosmic e-lab website, pupils can calculate the lifetime of the muon. As with most experiments, the more data you collect, the more accurate the result will be. I recommend recording about 24 hours of data. Because all signals from all 4 counters need to be recorded, the data file can quickly become too large for the website to handle, so more than 24 hours might not work.

### 4.1 Aim

The aim of this worksheet is to use your cosmic ray detector to calculate the lifetime of a muon.

### 4.2 Introduction

You have probably come across the idea in nuclear physics of radioactive isotopes. These are nuclei which are not stable, and will decay into different nuclei. A similar concept applies in particle physics. Not all particles are stable, and those which aren't will decay into different, lighter, particles. For example, when primary cosmic rays interact in the atmosphere, pions are created from the energy of the collision. These pions then decay into muons, and we detect the muons with our cosmic ray detectors. The characteristic time that it takes for a particle to decay is known as its lifetime, and the lifetime of a pion is  $2.6 \times 10^{-8}$  s. This is an extremely short lifetime, and so the pion will not travel very far towards the Earth before it decays. It is important to remember that this lifetime is only an average time before the pion decays. Some pions will decay well before this time and some will decay well after. However, there is a nice mathematical expression which describes the number of particles which decay in a certain time.



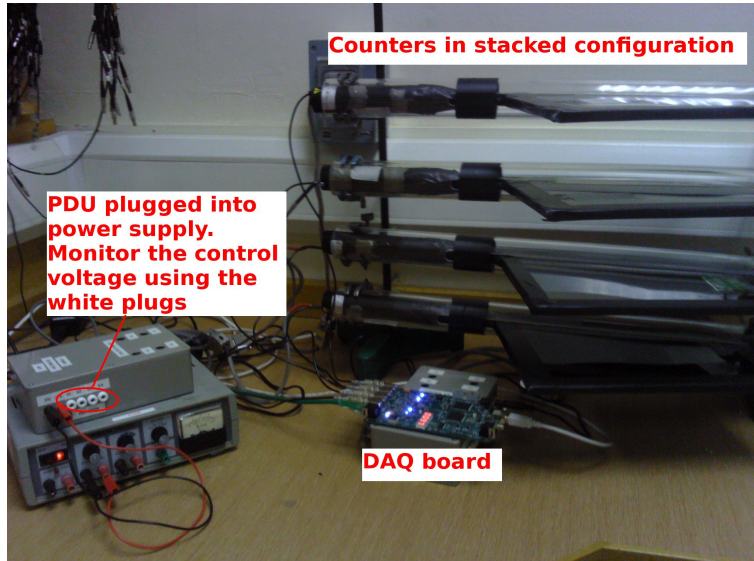
The graph above shows the typical shape we expect from the decay time of particles. The x-axis shows the time before the particle decays, and the y-axis shows the number of particles with this decay time. The general shape, common to all particle decays, is called an exponential decay, and has a very useful mathematical form:

$$N(t) = N_0 e^{-t/\tau} \quad (1)$$

$N(t)$  is what appears on the y-axis, the number of particles with a decay time larger than  $t$ ,  $N_0$  is the total number of particles detected,  $t$  is the decay time (the x-axis) and  $\tau$  is the lifetime of

the particle. Decays with different lifetimes will produce slightly different graphs. Knowing that this is the shape we expect means we can use our detector to draw a graph like this, and use it to work out what lifetime would produce that graph.

### 4.3 Measuring a Lifetime



In order to measure the decay time of a muon, we need it to decay actually inside our detector. To do this, set up the counters in the stacked configuration shown above. In order to make sure we have a muon which decays inside the detector, we need a coincidence between the first two or three counters and then no signal in the next counter. This would mean that a muon has passed through the first counters and then stopped within the detector. After a short period of time, the muon will decay into an electron, which will produce a signal in the counter which it stopped in. The time between the original coincidence signal and this second signal is therefore the decay time, which we can plot to see the exponential decay and measure the lifetime.

Of course it is not possible to make a muon stop inside the detector, nature has its own ideas of where the muons will stop. All we can do is look through all the events we record and try to find events which involve a muon stopping in the detector. As with any physics experiment you are likely to come across, the more events we use to make our measurement, the more accurate the measurement will ultimately be. Since it is quite rare to have a muon stop in the detector, we would recommend recording data over about 24 hours to make sure you have enough useful events to make your plot.

### 4.4 Running a Lifetime Study

We will first run a Lifetime study on data we have already taken so you can get used to using the website. Log onto the Cosmic e-lab website at <http://www18.i2u2.org/elab/cosmic/home/>. The data contains information on all pulses produced by each counter. The software then looks for events where 2 adjacent counters produced a coincidence, with no coincidence in the next counter. This is the indication that a muon has stopped in the detector, and the next signal in the second counter gives the decay time.

1. Click on the “Data” tab and then “Lifetime”.

The first screenshot shows the Cosmic Ray e-Lab homepage. The 'Data' tab is selected in the top navigation bar, and the 'Lifetime' sub-tab is also selected. Below the navigation bar, there is a section titled 'Lifetime: Choose data for lifetime study.' which includes a brief explanation of cosmic ray particles and a search interface. The search interface has a 'Quick Searches' section with 'Univ of Birmingham' selected, and an 'Advanced Search' section with 'Start Date' set to '08/16/2011' and 'End Date' set to '08/16/2011'. A red arrow points to the 'Search Data' button. Below the search results, it says 'Searching 37542 data files from 410 schools in 54 states.' and 'Search data from "Univ of Birmingham" on 16th August 2011'.

The second screenshot shows the same page after the search. The 'Analyze' button is circled in red, and a red arrow points to it from the text 'Select data from 16/08/2011 and click "Run lifetime study"'. The search results show 'Results 1-1 of 1 for school Univ of Birmingham (Searched 1 files in 0.023 seconds)'. Under 'Univ of Birmingham', there is a list of data files, and the file 'Aug 16' is selected, showing '4,403,679 events'.

2. Search for data from 19/08/2011 from the school “Univ of Birmingham”. Select the data from this day to analyse, as in the figures above.

Click **Analyze** to use the default parameters. Control the analysis by expanding the options below.

▼ **Analysis Controls**

? Coincidence level:  **Set coincidence level to 2**

? Gate width (seconds):  **Set gate width to 50  $\mu$ s**

? Number of Bins:

▼ **Plot Controls**

? X-min:

? X-max:

? Y-min:

? Y-max:

Plot Size:

Plot Title:

Figure caption:

▼ **Fit Controls**

? Fitting Turned On:  **Turn fitting on**

? X-min of fit:

? X-max of fit:  **Set max of fit to 50**

? Fit Y-intercept:  ? Alpha:

? Fit Lifetime:  ? Lifetime:

? Fit Background:  ? Background:

▼ **Execution Mode ?**

☒ Local (estimated time: 00:16:13)

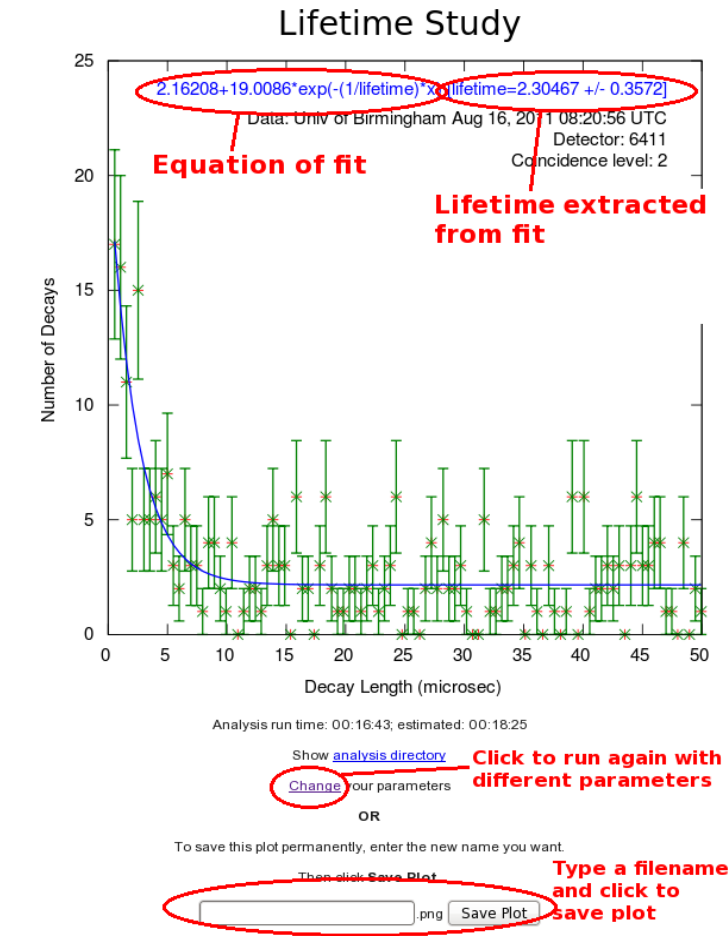
☐ I2U2 Cluster (estimated time: 00:30:52)

☐ Grid (temporarily disabled)

☐ Automatic (estimated time: 00:22:41)

**Click on analyze**

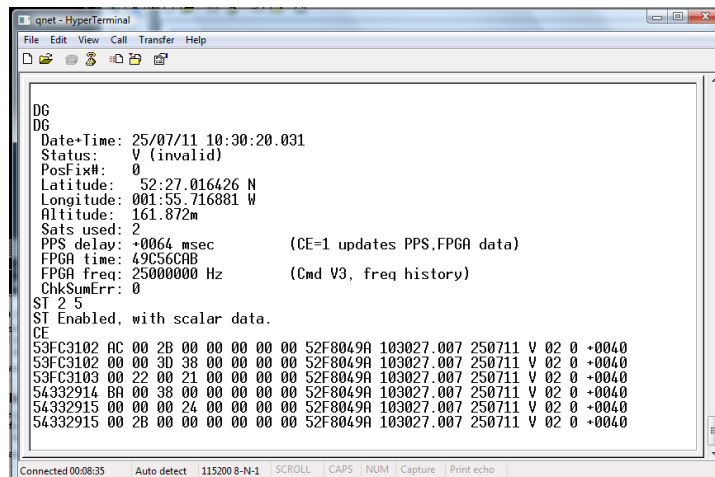
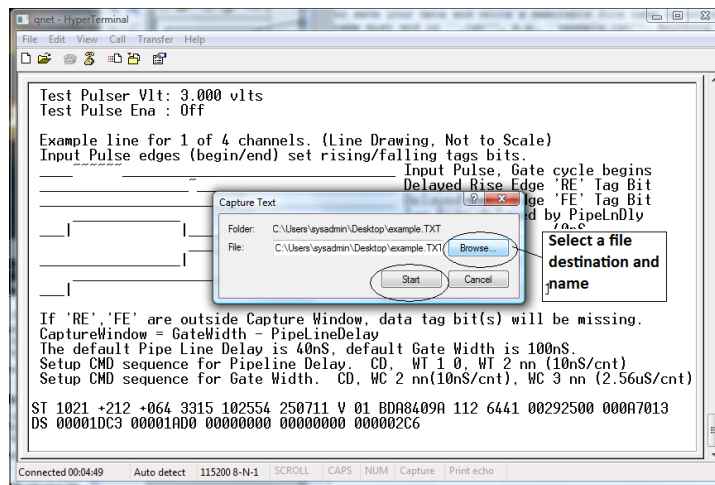
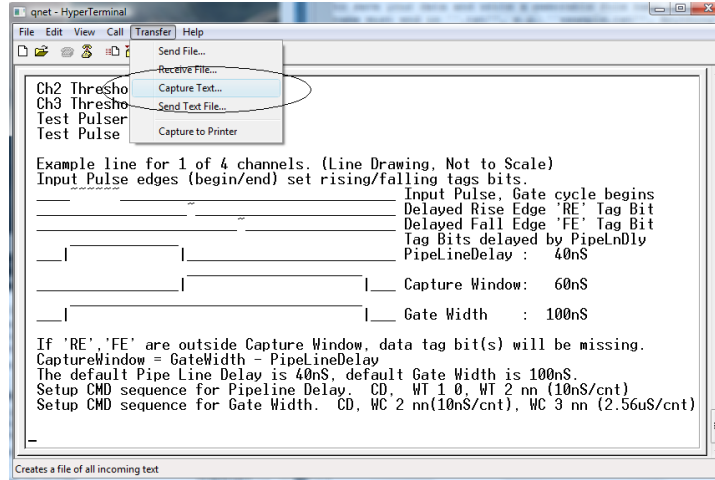
- Set the coincidence level to 2 so that the software will look for a coincidence in 2 adjacent counters followed by no signal in the next one. Expand the “Plot Controls” tab to change the range of the axes and the plot title. Expand the “Fit Controls” tab and make sure “Fitting turned on” is set to yes. If you want, you can make an estimate of the y intercept, the lifetime and the background for the plot fit. This could help to make your fit more accurate, but a bad guess could make it completely wrong. I would suggest leaving them blank unless the fit is not giving a sensible result. Once you have done that then click on “Analyze”.



You should obtain a plot similar to the one above. The green points are your plotted data and the blue line is the exponential decay line which has been fitted. The formula for this fit is written at the top of the plot, and tells you the best fit for the lifetime of the muon. This is given in microseconds ( $\mu\text{s}$ , which is 1 millionth of a second).

## 4.5 Collecting Data

Set up your counters in the stacked configuration and set the control voltages to the optimum voltages found by the plateau method. Open Hyperterminal and follow the steps below to collect data:



1. For the muon lifetime study we need all the data that we can get. We want to record all of the signals coming from the counters, not just the ones with coincidences. Type WC 00 0F

to look at 1-fold coincidences from all counters. We will use the analysis page of the website to search the data for coincidences at a later time.

2. From the “Transfer” menu select “Capture Text”
3. Choose a file name ending with “.txt” and save your file somewhere memorable. Then select “Start”
4. Anything which now appears in the Hyperterminal window will also be written to the “.txt” file. Start by typing the commands V1, V2, DG, ST 2 5. This ensures your data file contains the necessary information about the detectors.
5. Type the command CE to enable the counters and start writing data to the “.txt” file. Leave this running for about 24 hours to collect enough data. Make sure that the computer you are using is set to never sleep, otherwise you will not continue to collect data.
6. Once you have collected enough data type the command CD to stop writing out data.
7. From the “Transfer” menu select “Capture Text” and “Stop”.

Now you can use your data to repeat the steps above and calculate the lifetime of a muon. How does it compare to the true muon lifetime, which is  $2.2\mu\text{s}$ ? If it is wrong then it could be that you have to play about with the plot controls. Try changing the bin width, or using 2.2 as a starting point for the lifetime estimate.

*The next sections may be beyond the level of the pupils, but could provide some interest for the brighter students.*

## 4.6 Note on Uncertainties

You will notice that the lifetime is given to you as a number with some uncertainty, for example  $2.2 \pm 0.2\mu\text{s}$ . This uncertainty tells you how accurate the measurement you have made is. No experiment is perfect, and any measurement which you make will have an uncertainty associated with it. The better experiments will have a smaller uncertainty and so the value is more accurate. The technical definition of the uncertainty is that if you repeated the experiment a number of times, then on average the value you measure will be within these limits 68% of the time. So for the example above, if we repeat the experiment, we expect the value of the lifetime we measure to be within 2 - 2.4 68% of the time. So about a third of the time it will be outside these limits. We can use this to work out if our measurement is correct, and to quantify exactly how close to the true value it is. If it is only 1 or 2 times the uncertainty away from 2.2 then we can say confidently that our measurement is consistent and correct. If the uncertainty is 0.2 and our measured value is less than about 1.8 then we might start to worry that our measured value doesn't match the true value. Of course if the uncertainty is large then it will probably be consistent with the true value, but isn't very useful to us.

The more data we use, the smaller the uncertainty will be, so if your uncertainty seems particularly large, then try collecting more data.

## 4.7 A little bit of Special Relativity

We have already discussed the fact that muons are produced in the upper atmosphere, which is about 30km above sea level. If we assume that muons are travelling at the speed of light (which they very nearly are) then we can calculate how long they take to reach our detectors.

$$t = \frac{d}{v} = \frac{30 \times 10^3}{3 \times 10^8} = 100\mu\text{s} \quad (2)$$

So it takes  $100\mu\text{s}$  for the muons to reach our detectors. But this is much longer than the lifetime of the muons we just calculated, so most muons should decay before they reach us. So how is it

we are detecting them? For the answer we need to turn to Einstein's theory of Special Relativity. This theory includes a concept called time dilation which states that when something is travelling close to the speed of light, time appears to be dilated to an observer who isn't travelling fast. So if we were travelling with the muon, we would measure the time which passes before decay to be  $2.2\mu s$ . However, since we are a stationary observer, the time that the muons exist for seems to become longer. This is called time dilation. The exact amount that the time is extended by is determined by exactly how fast the muons are travelling, and can be calculated with the following formula:

$$t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}} \quad (3)$$

Muons are typically travelling at 99.9985% of the speed of light, so the time they actually exist for is:

$$t = \frac{2.2}{\sqrt{1 - 0.999986^2}} = 109 \times 2.2 = 415\mu s \quad (4)$$

which is plenty of time for the muons to reach our detectors before decaying.

So we need another experiment to prove that the muons are actually produced in the upper atmosphere, but if we assume that is true then my calculating the muons lifetime you can just prove that Einstein was correct in his theory of Special Relativity.

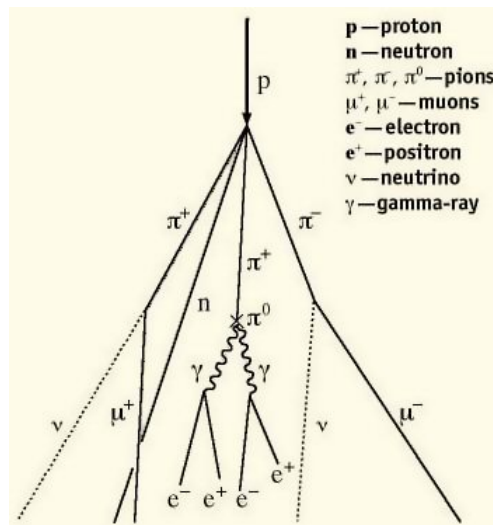
## 5 Worksheet 6: Shower Study

The sections uses the detectors in an unstacked configuration to detect cosmic ray showers. Once again, it requires about 10 hours of data to see many showers, but more accurate results can be obtained with more data. For each shower detected, the cosmic e-lab can provide information about the number of particles in the shower and the direction of the shower. Once again this is a great opportunity for pupils to write their own research proposal and investigate their own research question.

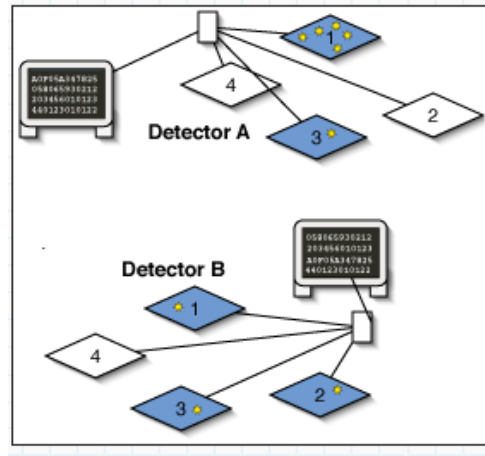
### 5.1 Aim

The aim of this worksheet is to investigate large cosmic ray showers and to find out where they come from and how they are produced.

### 5.2 What are air showers?



We have already discovered that cosmic ray muons are produced when primary cosmic rays interact in the atmosphere. However, there is often more than one particle produced in an interaction. Each of the particles which are produced will then interact with other molecules in the atmosphere to produce even more particles. With each interaction, the particles end up with a lower energy, until eventually there is not enough energy left to create more particles. The particles then decay, and you have a handful of muons produced by a single primary cosmic ray. This is called an Air Shower.



The muons will spread out as they travel towards Earth, but since they are all produced at the same time, they will reach sea level within about 100ns of each other. We can therefore spread our counters out flat, and see if we can detect a handful of muons arriving at the same time. We can then use the Cosmic e-lab website to analyse the data, and it will tell us how many muons were in the shower and what direction the shower came from.

The size of the air shower and the number of particles in the shower are determined by the energy of the primary cosmic ray. The higher the energy of the primary cosmic ray, the more particles there are and the further the shower spreads. There are sources of cosmic rays which produce particles with such high energy that the showers created are the size of a small town. The origin of these ultra high energy cosmic rays are still not fully known to physicists, but you can investigate them. If you know of some schools near you using the cosmic ray muon detector (CRMD) then you can organise yourself to take data at the same time. If you see a coincidence between signals in the detectors from different schools, then it is likely that you are detecting particles which are a part of the same large air shower, produced by an ultra high energy cosmic ray.

### 5.3 Performing a Shower Study



We will first analyse data which has already been recorded by the University of Birmingham to show you how a shower study is done. The counters were unstacked, as in the picture above, and covered an area of about  $0.5\text{m}^2$ . The data was recorded for about 24hours.

The image consists of two screenshots of the Cosmic Ray e-Lab website interface.

**Top Screenshot:** The 'Data' tab is selected in the top navigation bar. Below it, the 'Shower' sub-tab is highlighted. A red circle is drawn around the 'Shower' sub-tab. The main content area shows a search form with 'Univ of Birmingham' entered in the 'School' dropdown. The 'Start Date' is set to '08/13/2011' and the 'End Date' is also '08/13/2011'. A red arrow points to the 'Search Data' button. Below the search form, a red text overlay reads: "Search for School 'Univ of Birmingham' on 13th August 2011".

**Bottom Screenshot:** The search results are displayed. The 'Univ of Birmingham' search criteria are shown. The results list includes 'Detector 6411' with '5,336,249 events'. A red circle is drawn around the '6411' in the detector name. A red arrow points from this circle to the 'Run shower study' button in the 'Analyze' section on the right. A red text overlay reads: "Select data from 13/08/2011 and click 'Run shower study'".

Log into the cosmic e-lab website and select “Shower” from the “Data” tab. Change the dropdown menu to school and search for “Univ of Birmingham”. Select data from 13/08/2011 from detector 6411 and click on “Run shower Study”, as shown in the figures above.

Click **Analyze** to use the default parameters. Control the analysis by expanding the options below.

**Click on ? for information**

**▼ Analysis Controls**

? Center of graph view: Univ of Birmingham, Birmingham, GBR (6411) ▾

? Event Gate (ns): 100

? Detector Coincidence: 1

? Channel Coincidence: 4

? Event Coincidence: 4

**Set the Event Gate and coincidence levels**

**▼ Plot Controls**

? X-min:

? X-max:

? Y-min:

? Y-max:

? Z-min:

? Z-max:

Plot Size: Medium ▾

Plot Title: Shower Study

Figure caption: Data: Univ of Birmingham Aug 12, 2011 00:00:00 UTC  
Detector: 6411  
Event Coincidence: 4  
Detector Coincidence: 1

**▼ Execution Mode ?**

☒ Local (estimated time: 00:10:55)

☐ I2U2 Cluster (estimated time: 00:21:47)

☐ Grid (temporarily disabled)

☐ Automatic (estimated time: 00:17:02)

**Analyze** **Click on Analyze**

You can then change the coincidence levels. Click on the question mark by each setting for find out what it means. The detector coincidence is the number of different detector (i.e. different schools) you want the shower to have hit. Since we are just looking at one detector, set this to 1. The channel coincidence is the number of counters which need to be hit. Since we want all 4 counters to be hit to define an air shower, set this to 4. The event coincidence is the number of signals which are detected among the 4 counters within the gate width. Set this to 4 also. The value of the gate width should not affect how many particles you see in a shower, since they should all arrive within 100ns. Having a gate width which is too high can mean that you detect particles which are not part of the shower. Set the gate width to 100ns. You should not need to change the plot controls except to change the title of the plot. Once you have set the coincidences, click on “Analyze”.

Project Map

Library

Upload

Data

Posters

Site Map

Assessment

View Data

Performance

Flux

Shower

Lifetime

View Plots

Analyses

CRuob1 Log out

Shower study candidates (58)

Event Date	Event Coincidence	Detector Coincidence
Aug 12, 2011 05:22:27 UTC	8	1 (6411)
Aug 12, 2011 00:38:44 UTC	7	1 (6411)
Aug 11, 2011 13:55:13 UTC	7	1 (6411)
Aug 11, 2011 17:58:38 UTC	6	1 (6411)
Aug 12, 2011 09:17:46 UTC	6	1 (6411)
Aug 11, 2011 16:09:37 UTC	6	1 (6411)
Aug 12, 2011 07:20:04 UTC	6	1 (6411)
Aug 12, 2011 05:18:26 UTC	6	1 (6411)
Aug 12, 2011 05:10:13 UTC	6	1 (6411)
Aug 11, 2011 15:28:36 UTC	6	1 (6411)
Aug 12, 2011 03:29:14 UTC	6	1 (6411)
Aug 11, 2011 16:32:38 UTC	5	1 (6411)
Aug 12, 2011 11:28:10 UTC	5	1 (6411)
Aug 12, 2011 09:51:37 UTC	5	1 (6411)
Aug 12, 2011 10:08:02 UTC	5	1 (6411)
Aug 12, 2011 09:51:37 UTC	5	1 (6411)
Aug 12, 2011 09:29:44 UTC	5	1 (6411)
Aug 12, 2011 01:42:29 UTC	5	1 (6411)
Aug 12, 2011 01:14:14 UTC	5	1 (6411)
Aug 12, 2011 01:09:23 UTC	5	1 (6411)
Aug 12, 2011 01:08:44 UTC	5	1 (6411)
Aug 12, 2011 00:21:41 UTC	5	1 (6411)
Aug 12, 2011 00:07:22 UTC	5	1 (6411)
Aug 11, 2011 21:57:36 UTC	5	1 (6411)
Aug 11, 2011 21:28:57 UTC	5	1 (6411)
Aug 11, 2011 16:27:44 UTC	4	1 (6411)
Aug 11, 2011 16:17:09 UTC	4	1 (6411)

Click on an event to view the plot and information

Shower Study

Click to enlarge picture

View raw data or geometry for Aug 12, 2011 08:22:27 UTC for detector ID 6411

Plot datapoints:

East/West (meters)	North/South (meters)	Time (nanosec)	Detector Channel
-1.0	-7.6	0.0	6411 3
-0.9	-8.3	2.5	6411 1
-1.0	-8.8	3.7	6411 2
-1.1	-8.3	3.7	6411 4
-1.0	-8.8	23.8	6411 2
-0.9	-8.3	27.5	6411 1
-1.1	-8.3	38.8	6411 4
-1.0	-7.6	41.3	6411 3

Information about events in shower

View more events

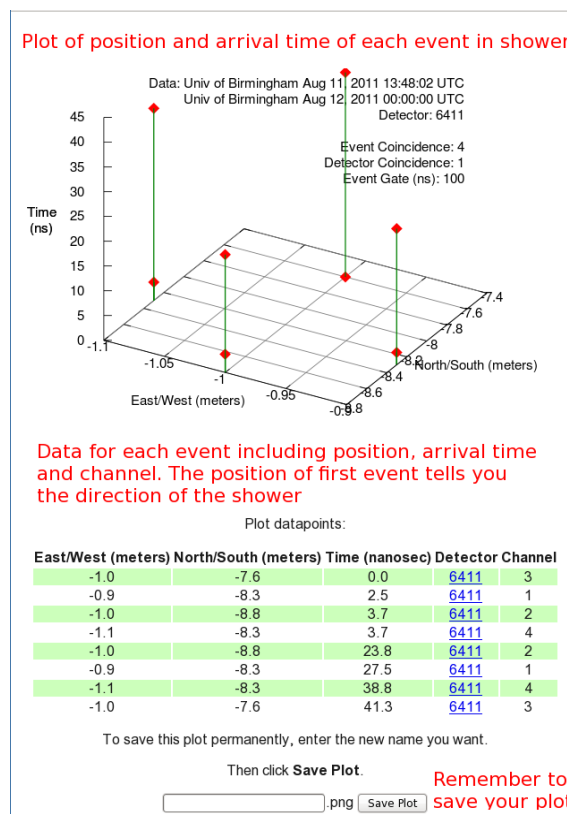
Analysis run time: 00:11:44; estimated: 00:19:37

Show shower analysis directory or event plot analysis.

Change parameters of study

Change your parameters

You will then see a page with all of the events which match your select criteria. They should therefore all be air showers. At the top of the page you will see the number of shower candidates. The list below tells you the date of the shower and the event coincidence, i.e. the number of particles in the shower. By clicking on an event, it will produce a plot of that event on the right hand side of the page. Click on the plot to make it larger.



You will now see a graph and a table of data for that particular study. The graph is a 3-dimensional plot of the shower. For each particle in the shower, the North/South and East/West measurement are plotted on the x- and y-axes and is determined by which channel the event was recorded in, and the geometry which you uploaded for the counter in that channel. The time of arrival is then plotted on the z-axis. This is relative to the time of the first signal, which has a time of 0.0ns. The position of the first signal tells you the direction of the cosmic ray shower. So for the plot above, the shower originated from the north. You can see a plot like this for each of the shower candidates by clicking on them from the page of events.

## 5.4 Your Own Investigation

Set up your counters in an unstacked configuration, as shown in section 5.3, and you can start your own shower study. You can be flexible with what it is you really want to investigate. Think about what might affect the air showers, or what properties of air showers you want to investigate, and come up with a research question. For example, what is the average number of particles in a shower? How is the shower affected if you move the counters further apart? Is there one particular direction that the showers tend to originate from? Is there a relationship between the number of particles in a shower and their direction? Try to come up with your own idea and then you are ready to start taking data. Open up Hyperterminal and follow the instructions below:

### 5.4.1 Upload Geometry

Before you start collecting data, be sure to upload your geometry with the new, unstacked configuration.

- To upload the geometry of the detector click on the upload tab on the e-lab website and then click on the geometry tab.
- Click on “add entry”. You should see the following pages.

**Cosmic Ray e-Lab**

Home Library **Upload** Data Posters Site Index Assessment

Detector 6430 Aug 16, 2010 @ 00:20

Please choose an action to your left.

Confused? Seeing errors? Please consult the [tutorial](#).

**Click to upload geometry**

---

**Cosmic Ray e-Lab**

Home Library **Upload** Data Posters Site Index Assessment

Detector 6430 Aug 16, 2010 @ 00:20

Edit Detector 6430 Entry Aug/16/10 @ 00:20 UTC:

Detector Configuration

Confused? Seeing errors? Please consult the [tutorial](#).

**Select channels used**

Active Channels: 1 ☒ 2 ☒ 3 ☐ 4 ☐

	Cable Length (m)	Area (cm <sup>2</sup> )	E-W (m)	N-S (m)	Up-Dn (m)
1	0.83	780.0	0.9	0.65	1.5
2	0.93	780.0	0.9	0.65	1.64
3					
4					

**Enter the details of each channel**

Orientation: ☒ Stacked ☐ Unstacked

**Select stacked or unstacked**

GPS Location

Latitude: 52.27.0222 N Longitude: 01.55.7221 W

e.g., 47:39.2347 N e.g., 122:18.68 W

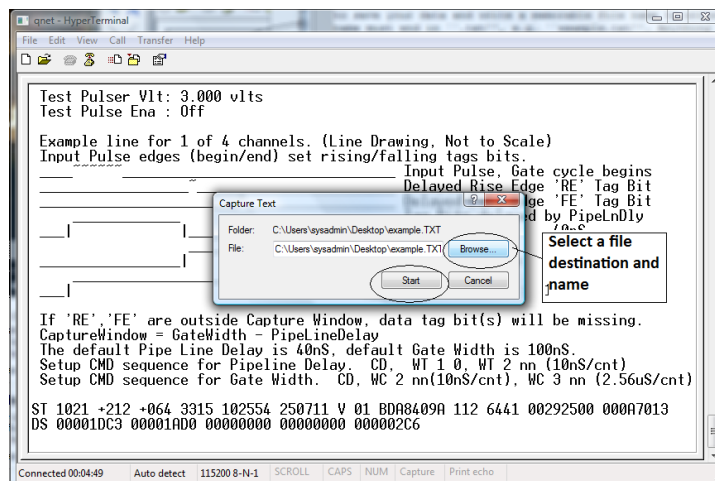
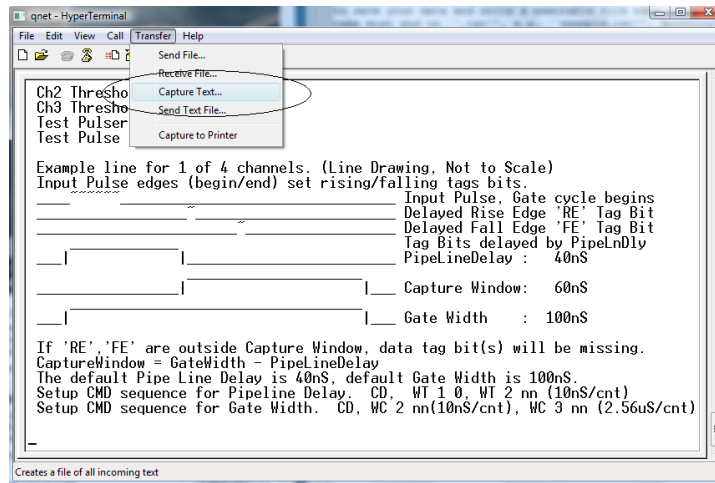
Altitude (m): 134 GPS Cable Length (m): 25.0

**Enter info from GPS**

Commit Geometry

- Fill in the details of the detector setup.
  - First, tick the boxes corresponding to the channels which you are using.
  - Next, enter the required details for each counter.
  - The cable length is the length of cable from the PMT to the DAQ board.
  - The area is the surface area of the counter in units of  $\text{cm}^2$ .
  - The E-W (East-West), N-S (North-South) and Up-Down measurements are the distances of the counters from the GPS antenna. In the stacked configuration, the Up-Down measurements for all counters should be the same.
  - Next you need to select the orientation of the detector. Select unstacked for a shower study.
  - Finally, you need to enter details of the GPS antenna. The longitude, latitude and altitude measurements can be found by typing the DG command into Hyperterm.
  - The GPS cable length is the length of cable connecting the GPS module to the DAQ board.

#### 5.4.2 Collecting Data



```

DG
DG
Date+Time: 25/07/11 10:30:20.031
Status: V (invalid)
PosFix#: 0
Latitude: 52:27.016426 N
Longitude: 001:55.716881 W
Altitude: 161.872m
Sats used: 2
PPS delay: +0064 msec      (CE=1 updates PPS,FPGA data)
FPGA time: 49C56CAB
FPGA freq: 25000000 Hz    (Cmd V3, freq history)
ChkSumErr: 0
ST 2 5
ST Enabled, with scalar data.
CE
53FC3102 AC 00 0B 00 00 00 00 00 52F8049A 103027.007 250711 V 02 0 +0040
53FC3102 00 00 3D 38 00 00 00 00 52F8049A 103027.007 250711 V 02 0 +0040
53FC3103 00 22 00 21 00 00 00 00 52F8049A 103027.007 250711 V 02 0 +0040
54332914 BA 00 38 00 00 00 00 00 52F8049A 103027.007 250711 V 02 0 +0040
54332915 00 00 00 24 00 00 00 00 52F8049A 103027.007 250711 V 02 0 +0040
54332915 00 2B 00 00 00 00 00 00 52F8049A 103027.007 250711 V 02 0 +0040

```

1. For a shower study we want to record all of the signals coming from the counters, not just the ones with coincidences. Type WC 00 0F to look at all signals from all counters. We will use the analysis page of the website to search the data for coincidences at a later time.
2. From the “Transfer” menu select “Capture Text”
3. Choose a file name ending with “.txt” and save your file somewhere memorable. Then select “Start”
4. Anything which now appears in the Hyperterminal window will also be written to the “.txt” file. Start by typing the commands V1, V2, DG, TL, ST 2 5. This ensures your data file contains the necessary information about the detectors.
5. Type the command CE to enable the counters and start writing data to the “.txt” file. Leave this running for about 24 hours to collect enough data. Make sure that the computer you are using is set to never sleep, otherwise you will not continue to collect data.
6. Once you have collected enough data type the command CD to stop writing out data.
7. From the “Transfer” menu select “Capture Text” and “Stop”.

Now that you have your data recorded on a file, you can upload it to the e-lab website for analysis.

- Click on the upload tab, and then click on data.
- Now select the file that you recorded the data and on click on “upload”.

Repeat the steps in section 5.3 and use the data you have collected to answer your research question and write up some conclusions.

## 6 Worksheet 7: Making a Poster

The cosmic e-lab website also allows you to create a poster to present your results. This is a great opportunity for pupils to present their findings from their own research topic to their fellow classmates. They can create a poster and then present it to the class with a short talk followed by time for questions. This is a nice way to round off the project and ensures that everybody learns about each part of the project. After the presentations they can then all take the post-test to see how much their knowledge has improved by taking the project.

### 6.1 Introduction

With any experiment, when you have finished analysing your results and have come up with a conclusion you will want to share your findings with the world. Science does not progress unless we tell people what we have done and what we found out. There are different ways we can do this. We can write a paper which is published in a journal. This is usually reserved for significant results. As well as this, we may also be lucky enough to be asked to give a presentation about our work at a major conference. This is a great way to tell people about our results as it also gives them an opportunity to ask us questions about our experiment. A much quicker and easier way of presenting our results is to make a poster. This very briefly outlines the experiment, and when small groups come round to look at it, we can discuss with them the procedure and results. You will now be making a poster to present to your fellow classmates. You should then prepare a 5 minute talk about your poster, explaining the experiment and your results. They will then have a question and answer session, where your classmates can ask you about the method and discuss with you your results.

### 6.2 Making your Poster

The screenshot shows the Cosmic Ray e-Lab website interface. At the top, there is a navigation bar with links: Project Map, Library, Upload, Data, Posters, Site Map, and Assessment. The 'Posters' link is highlighted with a red circle. Below the navigation bar, there is a sub-navigation bar with links: New Poster, Edit Posters, View Posters, Delete Poster, View Plots, and Upload. The 'New Poster' link is also highlighted with a red circle. Below this, there is a green banner that says 'New Poster: Make or edit your poster' and 'Click on "New Poster"'. To the right of the banner, there is a red circle around the 'New Poster' link in the sub-navigation bar, with a red arrow pointing to it and the text 'Click to view example poster'. Below the banner, there is a list of instructions for creating a poster. The first instruction is 'Fill in all the fields including Poster File Name if it is missing. This is the name the poster, do not use a name you have already used. Look at the [paradigms of a good poster](#) on an [excellent example](#)'. The second instruction is 'Be sure to write a good abstract'. The third instruction is 'To view the plots that you might want to include for the figures in your poster, click View Plots in the navigation bar. You can fill in fields for up to five figures. You don't have to fill them all in'. The fourth instruction is 'Click Make Poster to save the data for the poster and display your poster. If you have "pop-ups" blocked, you will need to click on Display Poster below'. Below the instructions, there is a form with the following fields: Poster File Name (e.g. poster\_lifetime), Title, Subtitle, Authors, Date (08/17/2011), Abstract (Brief Overview of purpose, procedures, results & conclusions), Introduction (Background and researchable question), and Procedure (Research or study plan). Each field has a text area and a toolbar with formatting options. To the right of the form, there is a red circle around the 'Make Poster' button, with a red arrow pointing to it and the text 'Fill in the fields for your poster'.

Cosmic Ray e-Lab

Project Map Library Upload Data **Posters** Site Map Assessment

**New Poster** Edit Posters View Posters Delete Poster View Plots Upload

New Poster: Make or edit your poster Click on "New Poster"

- Fill in all the fields including Poster File Name if it is missing. This is the name the poster, do not use a name you have already used. Look at the [paradigms of a good poster](#) on an [excellent example](#).
- Be sure to write a good abstract.
- To view the plots that you might want to include for the figures in your poster, click View Plots in the navigation bar. You can fill in fields for up to five figures. You don't have to fill them all in.
- Click **Make Poster** to save the data for the poster and display your poster. If you have "pop-ups" blocked, you will need to click on Display Poster below.

Poster File Name: (e.g. poster\_lifetime) Title Subtitle Authors Date: 08/17/2011

Abstract: (Brief Overview of purpose, procedures, results & conclusions)

Introduction: (Background and researchable question)

Procedure: (Research or study plan)

Click to view example poster

Fill in the fields for your poster

Figure7

Caption7

Figure8

Caption8

Figure9

Caption9

Figure10

Caption10

Conclusion:  
(Interpret results,  
suggest further  
study)

Bibliography

**Click on "Make Poster"  
If it doesn't show up you  
probably have pop-ups  
blocked so click on  
"Display Poster"**

To see poster, don't block popups! Otherwise click **Display Poster** below.

Making a poster is easy with the Cosmic e-lab. Log in and click on “New Poster” from the “Posters” tab. Now simply fill out all the fields, including a file name, the title and the authors names’. This section will give you advice about exactly what to write in each field. Once you have written everything you need to and uploaded your figures, click on “Make Poster” at the bottom of the screen. It will only appear if you do not have pop-ups blocked. If it does not appear automatically then click on “Display Poster”.

### 6.2.1 Abstract

In some ways the Abstract is the most important part of the poster. It is the first thing people read (after the title), and it is what they use to decide whether they are going to read the whole thing or not. It should not be too long, but should very briefly describe the experiment you carried out, and what your most important results and conclusions were. It is often useful to write this after you have written the rest of the poster, so that you can simply summarise the poster in a couple of lines.

### 6.2.2 Introduction

In the introduction you should write about the main physics behind the experiment. You should also discuss what your research question is, and what the ultimate goal of the experiment is.

### 6.2.3 Procedures

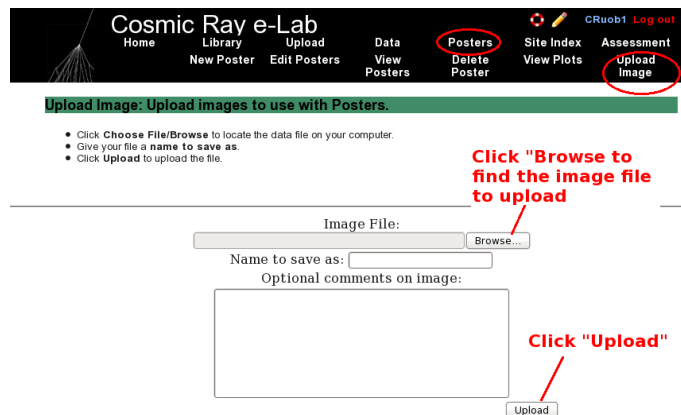
This is where you outline the method you used to carry out your research. It should not be step-by-step instructions, but should be detailed enough that somebody reading the poster will be able to understand how you attempted to answer your research question.

### 6.2.4 Results

This is where you discuss your results. You should state clearly what the data show and how you have interpreted it. You will also have to upload figures and plots after this section. Make sure these plots are relevant and that you refer to them in this section. You should explain your graphs and what the data shows.

### 6.2.5 Figures

You can include up to 10 figures for your poster, but 1 or 2 should be enough. Make sure your graphs are clear and are relevant to the poster. Include a caption to explain what the graph shows. You can include any of the graphs which you saved, so select the appropriate graph from the drop down list.



If you want to include a graph which is not saved in the Cosmic e-lab, for example if you used MS Excel to create a graph, then you will need to upload it before you can include it in a poster. You can do this by clicking on “Upload” under the “Posters” tab, as shown in the figure above. Click on “browse” to find the image you want to upload. It has to be saved as an image file, for example with a filename ending “.png” or “.jpg”. Once you have uploaded it, it will appear in the drop-down list of figures and you can include it in your poster.

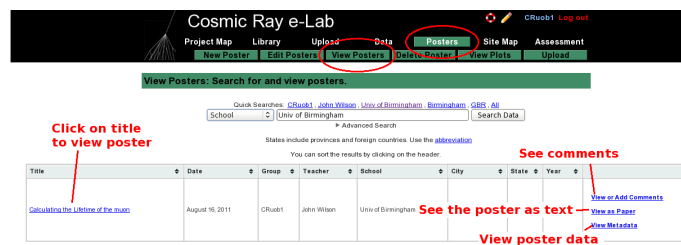
### 6.2.6 Discussions and Conclusions

This is where you interpret your results and give the answer to your research questions. Explain how the data presented in the results section supports these conclusions and why you have interpreted them in that way. What new physics do these conclusions imply? Afterwards you should suggest improvements to the procedure or extensions to the experiment. What can you now investigate knowing what you have learnt from this experiment?

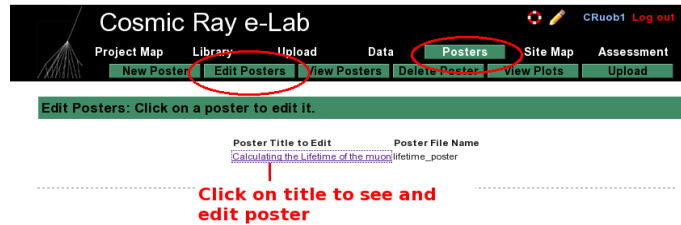
### 6.2.7 Bibliography

Include a list of any books or web pages that you used when researching material for this project.

## 6.3 Editing your poster



Once you have made your poster, you can view it by clicking on “View Posters” in the “Posters” tab. By searching for a school you can also view any other poster uploaded to the website. Just click on the title to view the poster. You can add comments to it by clicking on “View or add comments”. If you want to view the poster as a paper, so as plain text and figures, click on “View as paper”. If you want to view the data for the poster click on “View as Metadata”.

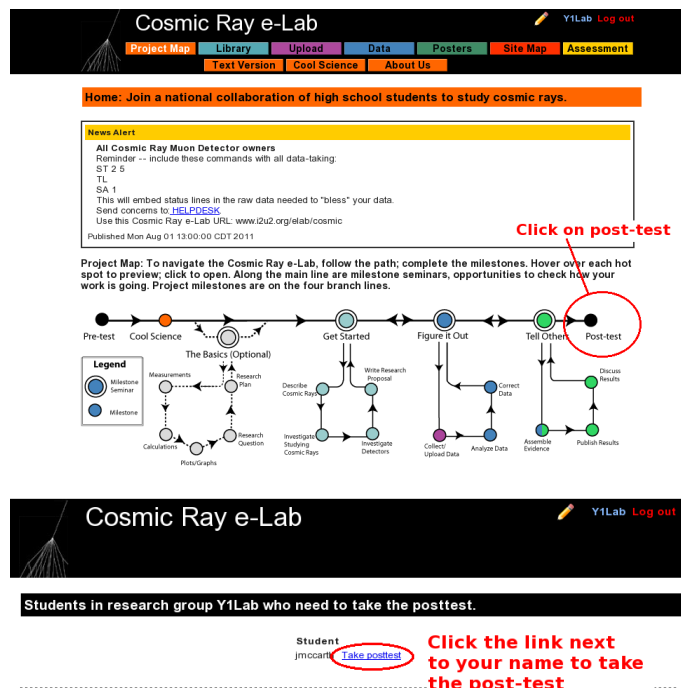


If you want to edit your poster, select “Edit Posters” from the “Posters” tab. Click on the title of the poster you wish to edit and it will bring up the fields for the poster, which you can edit. When you are done click on “Save Changes”.

## 6.4 Presenting your poster

When your poster is finished you can present it to the class. Prepare a 5 minute talk about your poster. Summarise each section but don’t just read the poster, try and explain it more clearly. When you are finished invite your classmates to ask you questions about the poster, either about the physics behind it, the procedure or the conclusions. They may have some insight which leads you to interpret the results slightly differently. You can then edit your poster based on their feedback.

## 6.5 Post-test



Finally, to round off the project, you will need to take to post-test. This is designed to test how much your knowledge has improved through the project, compared with the pre-test which you took. From the Project Map page, click on the post-test icon at the end. Then click the link next to your name to start the post-test.

## A Connecting the Muon Detector

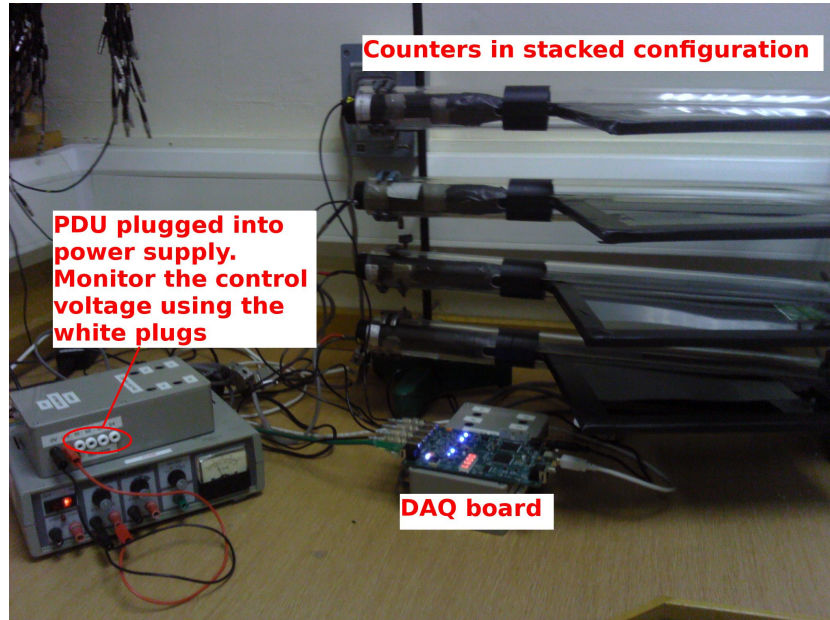


Figure 1: The setup for the muon detector.

### A.1 Downloading Drivers

The first thing you need to do is to download the drivers for the Data Acquisition Board (DAQ). The driver can easily be downloaded from <https://www.silabs.com/products/mcu/Pages/USBtoUARTBridgeVCPDrivers.aspx>. Select the driver for the operating system you are using and click the relevant link. The DAQ can now be used with the Hyperterm program, described in the next Appendix.

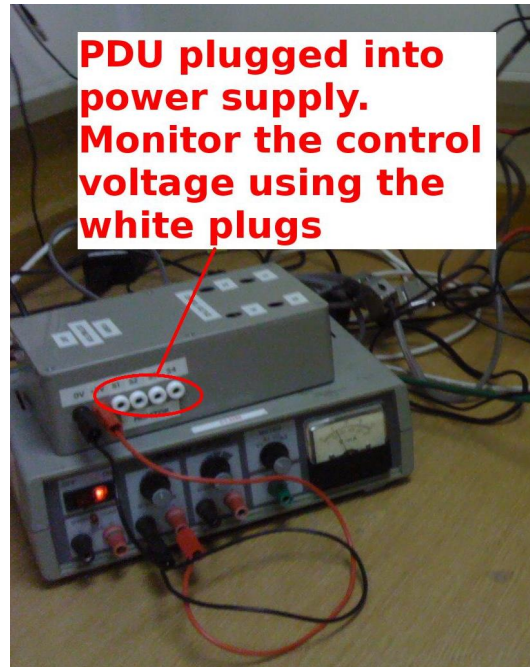
### A.2 Positioning the Counters



The counters should first be positioned one on top of the other. This can be done using retort stands. Support the clear tubes at either end, with the scintillators flat and at  $90^\circ$  to the retort

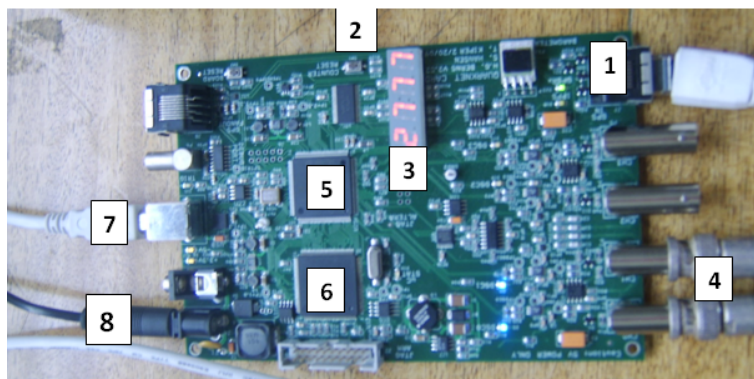
stand. The counters should be around 30cm apart.

### A.3 The Power Distribution Unit (PDU)



Connect the PDU to a power supply, as shown in the figure, and supply it with 5V. Note that supplying more than 5V can damage the PMTs. Connect the PMTs to the PDU via the 9 pin d-type connector. You can change the control voltage across the PMT by changing the variable resistor in the PDU. Use a digital voltmeter in the monitor points to test the control voltage on each counter. This should not go above 1.9V as it may damage the PMT.

### A.4 The DAQ board



The figure above shows the function of each part of the DAQ board. The numbers correspond to the following:

1. GPS Input.
2. Board reset button.
3. Coincidence counter display.

4. Inputs for 4 counters (channels 0-3).
5. CPLD (programmable fast logic).
6. Time-to-digital converter (TMC).
7. USB port (output to PC).
8. 5V Supply Input
  - Plug the 5V supply available for the DAQ board into point 8.
  - Connect the ethernet cable from the GPS module to point 1, which is the ethernet slot next to the PMT inputs. Place the GPS antenna at a window with a good view of the sky. When the GPS module flashes green with no red light, then it has fixed onto a satellite. This could take up to an hour. While the GPS has not fixed a position, the red LED on the GPS module will flash. Once a position has been fixed, the green LED on the GPS module will flash. In both cases the number of flashes corresponds to the number of satellites currently being used. You can also check the GPS status with the DG command through Hyperterm (see the worksheet 'Using Hyperterm').
  - Plug the signal wires from the counters into inputs at 4.
  - Plug the board into a USB port on the computer from point 7.

**Make sure everything is plugged in and you are ready to detect cosmic rays!**



## B Using Hyperterminal

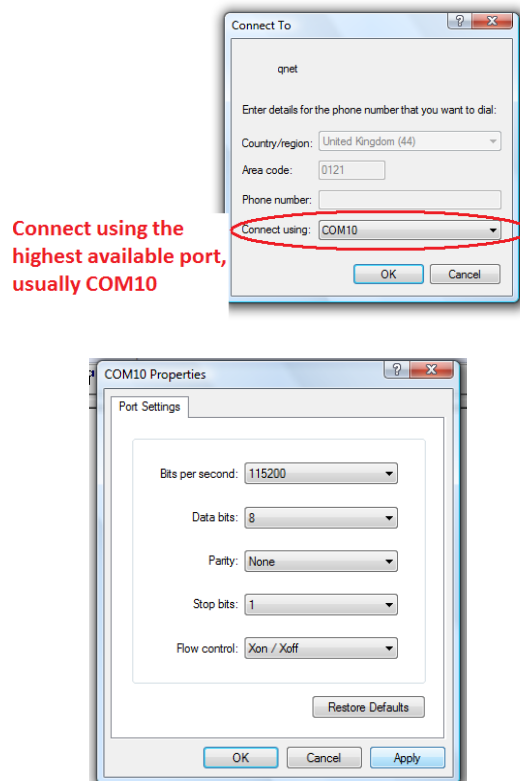
### B.1 Introduction

Hyperterminal is a terminal emulator program which we can use to send commands to the DAQ board. This is our way of interacting with the counters, and allows us to manipulate settings and to record the events we are detecting.

### B.2 Installing Hyperterm

Hyperterm is sometimes installed as standard on windows PCs. If it is then it can be found under “Accessories”, “Communications”. If it is not already installed, then we have a copy at the University of Birmingham which we can install for you. There may be a shortcut on your desktop for it.

### B.3 Opening Hyperterminal



Open hyperterminal and type a name for the connection (for example ‘qnet’). When asked to enter a phone number, change “Connect using” to the highest available port (usually COM10), and use the following settings:

- Bits per second: 115200
- Data bits: 8
- Parity: None
- Stop bits: 1
- Flow control: Xon/ Xoff

You can now send commands to the DAQ board to view and manipulate the settings of the counters.

## B.4 Hyperterminal Commands

```

V1
Run Mode      : On
Ch(s) Enabled : 1,0
Veto Enable   : Off
Veto Select   : Ch0
Coincidence 1-4 : 2-Fold
Pipe Line Delay : 40 nS
Gate Width    : 100 nS

Ch0 Threshold : 0.300 vlts
Ch1 Threshold : 0.300 vlts
Ch2 Threshold : 0.300 vlts
Ch3 Threshold : 0.300 vlts
Test Pulser Vlt : 3.000 vlts
Test Pulse Ena : Off

Example line for 1 of 4 channels. (Line Drawing, Not to Scale)
Input Pulse edges (begin/end) set rising/falling tags bits.
_____ Input Pulse, Gate cycle begins
_____ Delayed Rise Edge 'RE' Tag Bit
_____ Delayed Fall Edge 'FE' Tag Bit
_____ Tag Bits delayed by PipelineDelay
_____ PipelineDelay : 40nS
_____ Capture Window: 60nS
_____ Gate Width : 100nS

If 'RE', 'FE' are outside Capture Window, data tag bit(s) will be missing.
CaptureWindow = GateWidth - PipelineDelay
The default Pipe Line Delay is 40nS, default Gate Width is 100nS.
Setup CMD sequence for Pipeline Delay. CD, WT 1 0, WT 2 nn (10nS/cnt)
Setup CMD sequence for Gate Width. CD, WC 2 nn(10nS/cnt), WC 3 nn (2.56uS/cnt)
  
```

You can use the commands V1 and V2 to view the current settings of the detector. This is useful to check whether the commands you used to change settings have had the desired effect.

```

DG
DG
Date+Time: Status: V (invalid)
PosFix#:
Latitude: Longitude: Altitude: m
Sats used:
PPS delay: +0000 msec (CE=1 updates PPS,FPGA data)
FPGA time: 442CF900
FPGA freq: 2 Hz (Cmd V3, freq history)
ChkSumErr: 0
  
```

Using the DG command will display the settings of the GPS unit. You shouldn't start taking data until PosFix# = 1. This means that the GPS module has managed to fix on to a satellite, and this is important to make sure that the data we are recording is valid.

Some useful commands are listed at the end of the sheet, and are also available by using the H1 and H2 commands.

## B.5 Setting up the detector

The detector can be set up differently depending on the number of counters you are using, and the type of experiment you are doing. You can use Hyperterm to change the settings of the DAQ board to suit your experiment.

### B.5.1 Channels and Coincidences

For example, if you are using only two counters, you can set up the board to only use the required channels. In order to detect muons, we want to look for a coincidence between the signals from the two counters, indicating that a particle travelled through them at almost the same time. So for this setup, we say you need a two-fold coincidence between channels 0 and 1. To do this you use the command `WC 00 nm`. 'n' sets up an n+1-fold coincidence, so for a two-fold coincidence we use `n=1`.

m is a hexadecimal number representing the channels which are enabled and disabled. The pattern of enabled channels form a 4-bit binary number, with a 1 representing an enabled channel and 0 a disabled channel. So to enable all 4 channels the binary number is 1111, which is 15 in decimal, or F in hexadecimal. To enable channels 0 and 1, the binary number is 0011, which is 3 in hexadecimal. So to set up a two-fold coincidence between channels 0 and 1, we use the command `WC 00 13`. You can check this has worked with the `V1` command.

### B.5.2 Threshold

You can also change the level of the threshold of the DAQ board. The DAQ board will only register signals with a voltage above a certain level, known as the threshold. By default this is set to 300mV, but it can be changed using the `TL` command. You can also change each channel individually. So `TL n 300` set channel n to have a threshold of 300mV. Remember that the channels are labelled 0,1,2,3. Typing `TL 4 300` will set the threshold of all 4 counters at once. Just typing `TL` will display the value of the threshold for each channel.

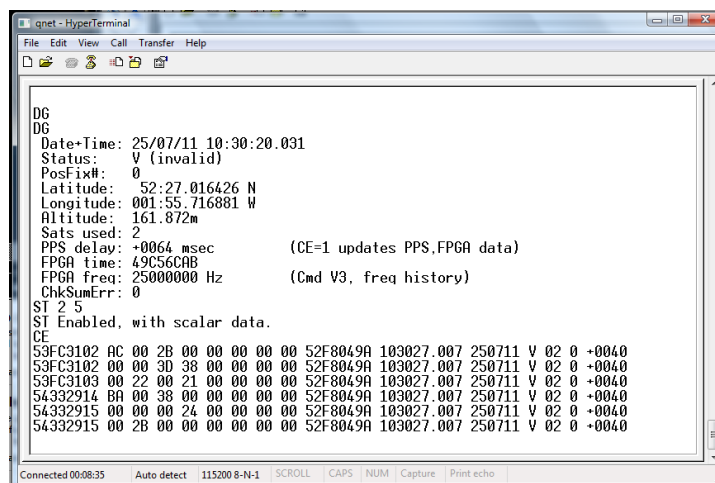
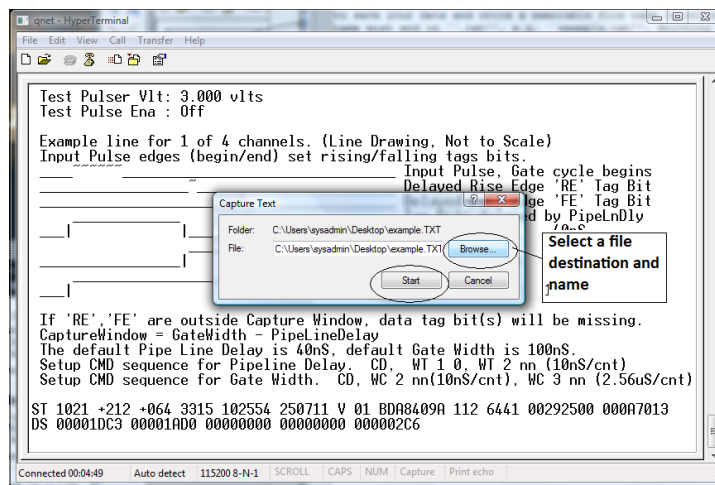
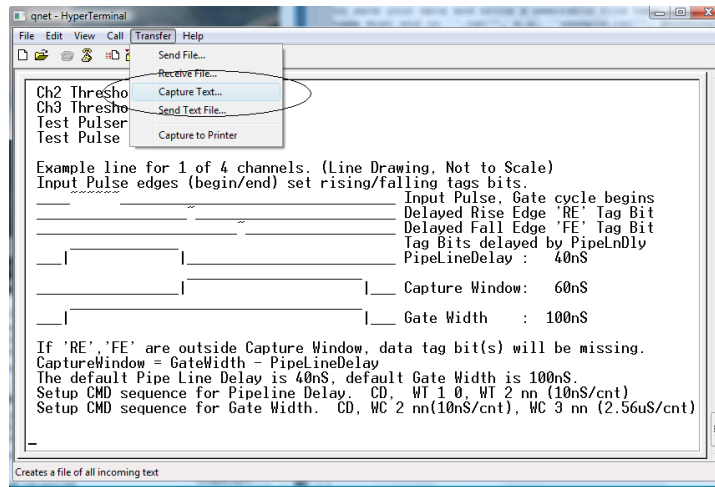
### B.5.3 Gate Width

The gate width is the largest time between signals for it to still be considered a coincidence. By default, this is set to 100ns. To change it you need two commands `WC 02 cd` followed by `WC 03 ab`. The combination `abcd` is the number of clock ticks required for the gate width. 1 clock tick is 10ns, so that a 100ns gate width requires 10 clock ticks. In hexadecimal, 10 is 000A, so to set this gate width, you need to type the commands `WC 02 00`, `WC 03 0A`.

### B.5.4 Save

To save the settings which you are using, type the command `SA 1`.

## B.6 Recording Data



1. From the "Transfer" menu select "Capture Text"
2. Choose a file name ending with ".txt" and save your file somewhere memorable. Then select "Start"

3. Anything which now appears in the Hyperterminal window will also be written to the “.txt” file. Start by typing the commands V1, V2, DG, ST 2 5. This ensures your data file contains the necessary information about the detectors.
4. Type the command CE to enable the counters and start writing data to the “.txt” file. Leave this running for about 24 hours to collect enough data. Make sure that the computer you are using is set to never sleep, otherwise you will not continue to collect data.
5. Once you have collected enough data type the command CD to stop writing out data.
6. From the “Transfer” menu select “Capture Text” and “Stop”.

<i>Command</i>	<i>Description</i>
H1, H2	<b>Help commands</b>
CD	<b>Counters Disabled:</b> Prevent event lines being written in hyperterm
DS	<b>Display Scalers:</b> shows the values of the scalers in a hexadecimal format
RB	<b>Reset Board:</b> resets the scalers
RE	<b>Reset Everything:</b> resets the whole board
TH	Shows values of the thermometer on the GPS module
BA	Read and adjust the barometer on the GPS module
DG	Displays information about the GPS module
V1, V2	View the registers
ST 3 5	Displays the status line every 5 minutes with counts and resets the counts. Using ST 2 5 doesn't reset the counters
SA 1	Save any changes to the settings.
WT 01 00 WT 02 nm	<b>Sets the TMC delay, d:</b> nm is the value entered in hexadecimal, and this will set the value of d as nm in decimal. (d is actually the difference between register 01 and 02)
WC 00 nm	<b>Sets the coincidence level and enables the desired counters:</b> n sets an n+1-fold coincidence (i.e. an event is recorded if there is a coincidence in signals between n+1 counters.) m is the hexadecimal number representing the channels on the DAQ board which are enabled. 1 represents an enabled counter and 0 represents a disabled counter. So to have all the channels enabled would be $1111_{bin}$ or $F_{hex}$
WC 02 cd WC 03 ab	Sets the value of the gate width, w. abcd represents the number of clock ticks required for the gate width (1 clock tick is 10ns). For example, a gate width of 100ns requires 10 clock ticks, which is 000A in hexadecimal, so you would use the command WC 02 00 followed by WC 03 0A.
TL n 300	Sets the threshold of channel n to 300mV. Using n=4 changes the threshold of all 4 channels at once.

